P³ User Manual

VERSION 1.0

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Table of Contents

List of Figures 4
List of Tables 5
1. Introduction 6
2. Using This Manual 8
2.1. Font Conventions 9
2.2. Acronyms 10
3. GPS Concepts and DGPS Positioning 11
3.1. GPS Overview 11
3.1.1. System 11
3.1.2. Concept of Positioning 11
3.1.3. GPS Signals 12
3.1.4. Positioning Services 12
3.2. Differential GPS 12
3.2.1. Advantages 12
3.2.2. Disadvantages 12
4. PPP Background 14
4.1. SPP 14
4.2. PPP 14
4.3. Precise Data 14
4.4. PPP Model Construction 15
4.4.1. Traditional Model 15
4.4.2. UoC Model 15
4.5. Point Real-Time Kinematic Positioning 16
4.5.1. Concept 16
4.5.2. Challenges 16
5. Quick Start Guide 18
5.1. Getting Data 18
5.1.1. GPS Observation and Broadcast Ephemeris Data 18
5.1.2. Precise Satellite Orbit and Clock Data 19
5.2. Entering Setup and Processing Parameters 20
5.3. Running P^3 22
6. Main Screen 24
6.1. P^3 Bars 25
6.1.1. Title Bar 25
6.1.2. Menu Bar 25
6.1.3. Button Bar 27
6.1.4. Status Bar 28
6.2. P^3 Processing Windows 28
6.2.1. Values Window 29
6.2.2. Sky Plot Window 31
6.2.3. Azimuth and Elevation Angles Window 33
6.2.4. Static/Kinematic Solution Window 34
6.2.5. Satellite Acceptance/Rejection Summary Window 35
6.2.6. Observation Residuals Window 37
6.3. Processing Progress Bar 38
7. System Modes 40
7.1. Post-Mission Processing 40
7.2. Real-Time Processing 40
8. Setup Parameters 41
8.1. Settings 41
8.1.1. Constants 42
8.1.2. Mask 42
8.1.3. Observables STD 42
8.1.4. Log File Path and Name 43

8.2. Antenna....44
8.2.1. Marker to ARP....44
8.2.2. ARP to APC....45
8.2.3. PCV File....46
8.3. Initial Coordinates....47
8.4. Meteorology....50
8.5. Satellite Exclusion....51
9. Processing Modes....53
9.1. SPP....53
9.1.1. SPP Post-Mission Processing....54
9.1.2. SPP Real-Time Processing....58
9.2. PPP....59
9.2.1. PPP Post-Mission Processing....60
9.2.2. PPP Real-Time Processing....63
9.3. Static Processing....65
9.4. Kinematic Processing....65
10. Processing Options....66
10.1. Traditional / UoC Model....66
10.2. Phase Smoothing of Code....66
10.3. Troposphere....66
10.3.1. Estimation....67
10.3.2. Modeling....67
10.4. Velocity Estimation....67
10.5. Block II/IIA Satellite Phase Centre Offset Correction....67
10.6. Filter Settings....69
10.7. Backward Processing....71
11. Processing Commands....72
11.1. RUN Button....72
11.2. PAUSE Button....72
11.3. STOP Button....72
12. Logging File....73
13. Report File....78
14. Graphs....81
14.1. Displaying Graphs....81
14.2. Selecting Between Graphs....82
14.3. Forward and Backward Processing....83
14.4. Graph Types....83
14.4.1. Position Error....83
14.4.2. Kinematic Solution Trajectory....87
14.4.3. Receiver Clock Offset....88
14.4.4. Zenith Troposphere Delay....88
14.4.5. Number of Satellites....89
14.4.6. Dilutions of Precision....90
14.4.7. Velocity....90
14.4.8. Ambiguity Changes....90
14.5. Printing Graphs....94
14.5.1. Print....94
14.5.2. Print Preview....95
14.5.3. Print Setup....98
Appendix A: P^3 Parameters and Default/Suggested Values....99
Appendix B: Ionospheric-Free Code and Phase Combinations....103
Traditional Model....103
UoC Model....104
Appendix C: Ambiguity Estimation in Traditional and UoC Models....105
Appendix D: Phase Smoothing of Code....107
Appendix E: References....108
Appendix F: PPP Publications....109

List of Figures

Figure 3.1: Concept of GPS positioning. 11
Figure 5.1: Filter Settings for static scenario. 22
Figure 5.2: DISPLAY menu and MOUSE menu 23
Figure 6.1: Main screen. 24
Figure 6.2: Title bar menu. 25
Figure 6.3: Menu bar options and their menus. 26
Figure 6.4: Button bar. 27
Figure 6.5: Status bar. 28
Figure 6.6: Values Window during processing 29
Figure 6.7: Sky Plot Window during processing. 31
Figure 6.8: Azimuth and Elevation Angles Window during processing 33
Figure 6.9: Static and Kinematic Solution Windows during processing. 34
Figure 6.10: Satellite Acceptance/Rejection Summary Window during processing. 35
Figure 6.11: Observation Residuals Window during processing. 37
Figure 6.12: Processing Progress bar 38
Figure 8.1: *Settings* tab in Setup window. 41
Figure 8.2: *Antenna* tab in Setup window 44
Figure 8.3: Parameters associated with TURBOROGUE AOAD / M_T antenna 46
Figure 8.4: Cartesian *Initial Coordinates* tab in Setup window 48
Figure 8.5: Ellipsoidal *Initial Coordinates* tab in Setup window. 48
Figure 8.6: *Meteorology* tab in Setup window 51
Figure 8.7: *Satellites Exclusion* tab in Setup window 52
Figure 9.1: SPP post-mission settings 54
Figure 9.2: Example of null epochs in observation files 56
Figure 9.3: SPP real-time settings 58
Figure 9.4: PPP post-mission settings 60
Figure 9.5: PPP real-time settings 63
Figure 10.1: IGS Conventional Antenna Phase Centres in Satellite Fixed Reference Frame 68
Figure 10.2: Satellite selection for BLOCK II/IIA offset correction 68
Figure 10.3: Filter Settings. 69
Figure 12.1: P^3 LOG file header. 73
Figure 12.2: Processing information for one epoch. 75
Figure 13.1: Report window. 78
Figure 13.2: Report file sample. 80
Figure 14.1: MOUSE and DISPLAY menus. 82
Figure 14.2: Position Error graph for forward processing. 84
Figure 14.3: Position Error graph for backward processing. 84
Figure 14.4: Position error statistics. 85
Figure 14.5: Position Error graph for all forward processing results. 85
Figure 14.6: Position Error graph for a subset portion of forward processing results. 86
Figure 14.7: Kinematic Solution Trajectory graph. 87
Figure 14.8: Receiver Clock Offset graph. 88
Figure 14.9: Zenith Troposphere Delay graph 89
Figure 14.10: Number of Satellites and Dilutions of Precision graph. 89
Figure 14.11: Velocity graph. 90
Figure 14.12: Ambiguity Changes graphs for L1, L2 and L1 & L2. 91
Figure 14.13: Ambiguity Changes graph for the Traditional Model. 92
Figure 14.14: Ambiguity Changes graph for the UoC Model for L1 & L2. 93
Figure 14.15: Show Ambiguity window 93
Figure 14.16: Print window. 94
Figure 14.17: Portrait preview window. 96
Figure 14.18: Landscape preview window. 97
Figure 14.19: Print Setup window. 98

List of Tables

Table 2.1: Font conventions used in the manual....9
Table 5.1: Initial receiver coordinates and antenna parameters for CRO1. 19
Table 5.2: Settings parameter values. 20
Table 5.3: Antenna parameter values. 20
Table 5.4: Initial Coordinate parameter values. 20
Table 5.5: Meteorology parameter values. 21
Table 5.6: PPP window parameter values....21
Table 6.1: Values Window parameter descriptions. 29
Table 6.2: Description of satellite status colours. 32
Table 6.3: Residual types and their processing modes. 37
Table 8.1: Computation of standard deviations. 43
Table 10.1: Processing options and their modes. 66
Table 10.2: Availability of Initial STD and Spectral Density parameters. 70
Table 10.3: Sample Initial STD and Spectral Density values for static processing. 70
Table 10.4: Sample Initial STD and Spectral Density values for kinematic processing. 70
Table 12.1: Additional parameter listings one processed epoch. 76
Table 14.1: Graphs and their modes. 83
Table A.1: P^3 parameters. 99

1. Introduction

This manual is a guide for operating P^3 – a program that implements Precise Point Positioning (PPP) technology, allowing users to achieve centimetre to decimetre positioning accuracy with a single GPS receiver. It was developed in the Department of Geomatics Engineering at the University of Calgary.

Contained in this manual are descriptions of the various features and processing modes available in P^3, as well as in-depth explanations of the parameter values that need to be entered by the user when processing the data.

The program consists of a single main screen where information is displayed during processing. Various graphs can be activated after processing, including a graph of the position error with respect to initial coordinates, the kinematic solution trajectory, the number of satellites used in processing, the various dilutions of precision, the receiver clock offset and the zenith troposphere correction.

This version of P^3 only implements post-mission processing. Although real-time processing has been developed and its functions have been described in the manual, it is available only as an option and is disabled in the current version. Reasons for this can be found under the 'Real-Time Corrections' heading below. For users who are interested in the real-time processing functions of P^3, please contact Dr. Yang Gao, Department of Geomatics Engineering, The University of Calgary, 2500 University Drive, NW, Calgary, Alberta, Canada T2N 1N4, gao@geomatics.ucalgary.ca.

Processing can be done in either static or kinematic mode. Two point positioning modes are available: Single Point Positioning (SPP), which makes use of code measurements only, and Precise Point Positioning (PPP), which predominantly makes use of phase measurements. In PPP mode, backward processing can also be performed to achieve better positioning accuracy.

MOTIVATION FOR P^3

Autonomous point positioning was the original aim of GPS. However, due to errors caused by satellite ephemerides, satellite clock corrections, ionosphere, troposphere, multipath and noise, the accuracy of autonomous point positioning cannot be better than a couple of metres, even after Selective Availability (SA) was turned off.

Nowadays, with the emergence of Point Real-Time Kinematic (P-RTK) positioning, a lot of attention is again focused on standalone positioning. This method arose from the advent of precise ephemeris and satellite clock corrections. The concept behind this method is to make use of un-differenced code and carrier phase observations along with precise corrections to get the best accuracy out of GPS. All components of P-RTK have been incorporated in P^3. The software is portable, user-friendly, and contains many graphical interface tools for analyzing data.

REAL-TIME CORRECTIONS

Processing in real-time requires real-time corrections. The software was initially configured to accept real-time GPS corrections from Natural Resources Canada (NRCan) and from the Jet Propulsion Laboratory (JPL). Both provide real-time corrections that must be applied to broadcast orbit and clock data, and are described below.

Since both sets of real-time corrections (NRCan via the Internet or JPL via the Internet) are not freely available to the public, permission must be obtained for access to the above real-time corrections. For users who are interested in the real-time processing functions of P^3, please contact Dr. Yang Gao, Department of Geomatics Engineering, The University of Calgary, 2500 University Drive, NW, Calgary, Alberta, Canada T2N 1N4, gao@geomatics.ucalgary.ca.

GPS•C

NRCan corrections are called GPS•C, and are provided through the Canada-wide Differential GPS (CDGPS) service. These corrections are generated from a network of real-time GPS tracking stations distributed throughout Canada. Computing facilities in Ottawa gather the data from these stations using high-speed communication links, and upload the corrections to the geostationary MSAT-1 L-band satellite, which then broadcasts the corrections to all of Canada and territorial waters.

GPS•C provides enhanced real-time positioning by applying corrections to user broadcast orbit and clock information. The real-time GPS correction service is based on the Canadian Active Control System (CACS). Precise satellite ephemerides, clock corrections, and Earth orientation parameters are generated with a precision of about 10 cm, 1 ns and 0.2 mas, respectively.

Two types of real-time corrections are available from NRCan: via Internet and via CDGPS radio units. P^3 software was developed to work with the Internet corrections. Since the introduction of the CDGPS radio units, it was found that the received corrections from the radio units are not in the same format as those previously obtained over the Internet. Currently, the new format has not been integrated into P^3.

More information about these corrections can be obtained from *www.cdgps.com*.

JPL

JPL is a federally funded research and development facility managed by the California Institute of Technology (CALTECH) for the National Aeronautics and Space Administration (NASA). Real-time corrections developed by JPL are also referred to as Global Differential GPS (GDGPS) corrections, and are distributed via the Internet. JPL corrections are not freely available.

FILE FORMATS AND RECEIVERS

Currently, only the RINEX file format is supported for observation files and GPS navigation files. Furthermore, only Javad receivers can be used for real-time applications. More receivers will be added in the near future and incorporated into subsequent versions of the software.

2. Using This Manual

FONT CONVENTIONS AND ACRONYMS

Font conventions used throughout this manual, as well as a listing of acronyms are given in Sections 2.1 and 2.2, respectively

GPS AND PPP BACKGROUND INFORMATION

Section 3 of this manual provides some background information on the Global Positioning System (GPS) as well as a short description of the Differential GPS (DGPS) methodology. The advantages and disadvantages of this method are examined, which leads to the introduction of Precise Point Positioning (PPP) in Section 4.

Although a full theoretical discussion of PPP is not presented in this manual, various un-differenced ionospheric-free code and phase combinations, which are used in the Traditional and UoC Models, are presented in Appendix B.

QUICK START GUIDE

A quick start guide has been included in this manual in Section 5, allowing users to run P^3 quickly to see its various functions and features without having to read the entire manual.

GPS observation files in RINEX format can be downloaded for free from the Scripps Orbit and Permanent Array Center (SOPAC) website. Precise satellite clock and orbital corrections can be obtained from the International GPS Service (IGS) website. Parameters necessary to run the program are also provided in this section.

MAIN SCREEN, SYSTEM MODES AND SETUP

The main screen and its associated processing windows are described in Section 6, along with information about the Title, Menu, Button, and Status bars. In Section 7, the two system modes, post-mission and real-time, are described. Section 8 outlines the various setup parameters that need to be specified regardless of the processing mode chosen. This includes parameters associated with settings, antenna, initial coordinates, meteorology, and satellite exclusion.

PROCESSING MODES

In Section 9, the various processing modes are described. SPP or PPP processing in either static or kinematic mode is supported.

PROCESSING OPTIONS

In Section 10, processing options are explained. The user can choose between the Traditional Model and the UoC Model for implementing PPP. Furthermore, the user can specify troposphere estimation as opposed to troposphere modeling, phase smoothing of code, the satellites for which the phase centre correction should be applied and values associated with the processing filter. Velocity estimation and backward processing are also described in this section.

PROCESSING COMMANDS AND OUTPUT

Section 11 lists the three available processing commands: *RUN, PAUSE,* and *STOP*. Processing output is described in Sections 12, 13 and 14. Three forms of output can be generated: a logging file (Section 12), a report file (Section 13), and a graphical representation of the various quantities computed during processing (Section 14). The logging file is created automatically. It lists the parameters that were used in the last program run along with processing information for each epoch. The report file can optionally be created by the user, which will list the various quantities for each processed epoch in a convenient format. Both output files are in ASCII text format.

APPENDICES

Appendix A provides a comprehensive listing of all parameters that may be specified in P^3. The type of value that is to be input for each parameter is provided, as well as a range of acceptable values. Default values are also listed. In Appendix B, various un-differenced ionospheric-free code and phase combinations are presented for the Traditional and UoC Models. Appendix C provides an overview of ambiguity estimation in PPP mode for the Traditional and UoC Models. Finally, Appendix D provides a brief description of the process that is used to smooth unambiguous but noisy code data with ambiguous but less noisy carrier phase data. References used for some technical descriptions presented in the manual are provided in Appendix E. Finally, Appendix F lists various Precise Point Positioning publications.

2.1. Font Conventions

Throughout this manual, several font conventions have been adopted to help differentiate between file, menu, button, window, tab, parameter and graph names. These and other font conventions are listed in Table 2.1.

Table 2.1: Font conventions used in the manual.

Font Convention	Description
Italicized bold text	Used for file names, for example, a RINEX file containing satellite observations is denoted as ***algo1200.03o***.
BOLD CAPITALIZED TEXT	Used for menu names, for example, the **HELP** menu.
ITALICIZED CAPITALIZED TEXT	Used for button names, for example, the *REPORT* button.
Bold text	Used for window names, for example, the **Setup** window.
Italicized text	Used for tab names, for example, the *Initial Coordinate* tab in the **Setup** window.
ALL CAPITALIZED TEXT	Used for parameter names, for example, the ELEVATION MASK parameter in the *Settings* tab of the **Setup** window.
Underlined bold text	Used for graph names.
Underlined text	Used for website links.
Underlined italicized text	Used for Internet addresses.

2.2. Acronyms

APC	Antenna Phase Centre
ARP	Antenna Reference Point
ASCII	American Standard Code for Information Interchange
C/A	Coarse Acquisition
CACS	Canadian Active Control System
CALTECH	California Institute of Technology
CDGPS	Canada-wide Differential GPS
DMS	Degrees, Minutes, Seconds
DoD	Department of Defense
DGPS	Differential GPS
DOP	Dilution of Precision
DRMS	Distance Root Mean Square
EFEC	Earth-Fixed Earth-Centered
GDGPS	Global Differential GPS
GDOP	Geometric Dilution of Precision
GGN	Global GPS Network
GPS	Global Positioning System
GPS·C	GPS Correction (Service)
GSD	Geodetic Survey Division
IGS	International GPS Service
ITRF	International Terrestrial Reference Frame
JPL	Jet Propulsion Laboratory
NASA	National Aeronautics and Space Administration
NRCan	Natural Resources Canada
OTF	On-the-fly
P-Code	Precise Code
PCV	Phase Center Variation
PDOP	Position Dilution of Precision
PPP	Precise Point Positioning
PPS	Precise Positioning Service
PRN	Pseudo Random Noise
P-RTK	Point Real-Time Kinematic
RINEX	Receiver Independent Exchange Format
RMS	Root Mean Square
RTG	Real-Time GIPSY (software)
RTK	Real-Time Kinematic
RTNT	Real-Time Net Transfer (software)
SA	Selective Availability
SOPAC	Scripps Orbit and Permanent Array Center
SPP	Single Point Positioning
SPS	Standard Positioning Service
STD	Standard Deviation
TEC	Total Electron Content
VC	Variance-Covariance (matrix)

3. GPS Concepts and DGPS Positioning

This section provides a brief overview of the Global Positioning System (GPS) and the concept of Differential GPS (DGPS). The advantages and disadvantages of DGPS are presented, which then leads to the concept of Precise Point Positioning (PPP), described in Section 4.

3.1. GPS Overview

In this section, a brief overview of GPS and the concept of positioning, GPS signals, and positioning services is provided.

3.1.1. System

GPS is a satellite-based, all weather, line-of-sight radio navigation and positioning system funded and controlled by the U.S. Department of Defence (DoD). It is nominally formed from a constellation of 24 satellites and their ground stations. There are six orbital planes, spaced sixty degrees apart, and inclined at about fifty-five degrees with respect to the equatorial plane.

3.1.2. Concept of Positioning

The concept of positioning with GPS is based on simultaneous ranging to at least four GPS satellites, as shown in Figure 3.1. With known satellite coordinates, the three-dimensional coordinates of the receiver can be determined along with the receiver clock offset.

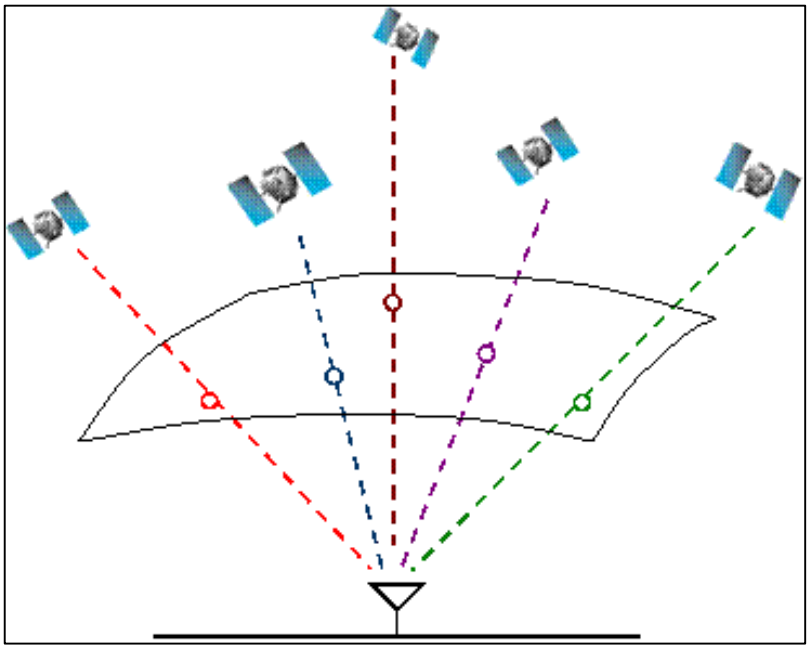


Figure 3.1: Concept of GPS positioning.

3.1.3. GPS Signals

GPS satellites continuously transmit microwave carrier signals on two frequencies: L1 at 1575.42 MHz, and L2 at 1227.60 MHz. These signals are modulated with one or two pseudorandom noise (PRN) sequences known as the Course Acquisition (C/A) code and the Precise (P) code. The chipping frequencies of these signals are 1.023 MHz and 10.23 MHz, corresponding to chip lengths of approximately 300 m and 30 m, respectively. Both the C/A code and the P code are modulated on the L1 carrier, while the L2 carrier is only modulated by the P code. A 50 Hz navigation message is also modulated on the signals, which consists of data bits that describe the GPS satellite orbits, clock corrections, and other system parameters such as satellite health.

3.1.4. Positioning Services

Both C/A code and P code allow for the determination of time and position, but with different precisions. The initial design goal of the system was to provide two Single Point Positioning (SPP) services: the Standard Positioning Service (SPS) with C/A code for civilian users, and the Precise Positioning Service (PPS) with P code for U.S. military and authorized users. Both services utilize only one receiver and are subject to the effects of all GPS error sources.

SPS and PPS still cannot support metre-to-millimetre level positioning in navigation applications, such as geodetic survey, precise farming, and aircraft landing. Fortunately, the GPS system can do much more than just SPS and PPS. After over 20 years of development, with the participation of scientists from all around the world, GPS has matured into a technology that goes far beyond its original design goals. The key breakthrough has been the development of DGPS.

3.2. Differential GPS

In this section, the advantages and disadvantages of DGPS are described.

3.2.1. Advantages

DGPS is an advanced positioning technique in which base station(s) with precisely known coordinates are required for rover receivers to achieve high accuracy. It can provide accuracy ranging from a couple of metres to several millimetres, depending on the receiver equipment and the type of GPS measurements used [Abousalem, 1996]. It is built on the fact that major GPS error sources are spatially correlated and can be fully or partially removed by differencing techniques. Since its introduction, DGPS has received widespread acceptance for applications with high accuracy needs.

3.2.2. Disadvantages

Although DGPS can provide high accuracy positioning, it requires:

- Simultaneous observations at the rover and base station(s).
- Limited separation between the rover and base station(s) (typically not more than 20 kilometres).

The requirements for the deployment of base station(s) and the spatially limited operating range of the rover have increased the operational cost and logistical complexity in the field. As such, the full adoption of Real-Time Kinematic (RTK) technology has been limited in many applications. Therefore, researchers have started looking for new positioning techniques that can offer global consistency and high positioning accuracy without using reference stations.

4. PPP Background

In this section, the basic ideology behind Precise Point Positioning (PPP) is presented. First, the shortcomings of Single Point Positioning (SPP) are described. Then, the concepts behind PPP, precise data suppliers, as well as advances in PPP model construction are briefly presented. Details associated with the Traditional Model and the UoC Model are provided. Finally, the concepts and challenges of Point Real-Time Kinematic Positioning (P-RTK) are described.

4.1. SPP

Conventional SPP, which was initially designed for GPS, is subject to the influence of all error sources. Major error sources include those introduced by broadcast orbits and clocks, as well as atmospheric effects. Since SPP is only able to provide position solutions with an accuracy level of several metres, it is not suitable for various applications.

4.2. PPP

The advent of precise orbit and clock correction products with centimetre level accuracy has significantly reduced the errors associated with satellite orbit and clock determination. Once orbit and clock errors are substantially reduced using precise data, higher positioning accuracy can be expected even when a single GPS receiver is used.

The method that derives high precision positioning solutions by processing un-differenced carrier phase observations from a single GPS receiver assisted with precise orbit and clock corrections is called Precise Point Positioning (PPP). The word "precise" is used to distinguish it from the conventional SPP method. Dual-frequency receivers are used for PPP to eliminate the effect of the ionosphere since no differencing of observations is done.

PPP has received increased attention in the past several years within the GPS community due to its great operational flexibility and accuracy promise. The major advantages of PPP lie in two aspects: system simplicity at the user's end, and global consistency in terms of positioning accuracy.

If ambiguity resolution of un-differenced carrier phase observations becomes feasible, the PPP method will be ready to support the development of new RTK systems using a single receiver without the need for base station(s).

4.3. Precise Data

To date, there are many organizations, including IGS, NRCan and JPL, which offer precise data in post-mission and real-time. IGS provides precise satellite orbit and clock data with different precisions and latencies. As of November 23, 2003, they are: *ultra-rapid corrections* with accuracies of less than 5 cm and 0.2 ns, with a latency of 3 hours, *rapid corrections* with accuracies of less than 5 cm and 0.1 ns, with a latency of 17 hours, and *final corrections* with accuracies of less than 5 cm and less than 0.1 ns, with a latency of 13 days. JPL and NRCan

provide real-time satellite orbit and clock corrections over the Internet, which can then be applied to broadcast orbits and clocks. These are described in more detail in the Introduction (Section 1).

4.4. PPP Model Construction

Ever since its introduction, PPP has shown great potential to become a high precision positioning technology. Several developments in PPP model construction have been made. These include metre level positioning accuracy based on GPS code measurements [Lachapelle, 1995], and centimetre level positioning accuracy based on phase observations in the PPP Traditional Model [Kouba, 2000; Muellerschoen, 2001]. The latter research has attracted much attention from the GPS community because it shows that the single-receiver positioning approach can achieve centimetre level positioning accuracy, which is comparable to DGPS.

4.4.1. Traditional Model

In the implementation of the PPP Traditional Model, both code and phase observations from a dual-frequency receiver are used as basic observables to generate ionosphere-free combinations. These combinations are shown in Appendix B.

The PPP Traditional Model is easy to implement but has two disadvantages. First, the ambiguity term in the model is a non-linear unknown consisting of both L1 and L2 carrier phase ambiguities. As a result, only a float solution can be obtained since this combined term does not preserve the integer characteristics of the carrier phase ambiguity. Therefore, ambiguity resolution algorithms cannot be implemented based on the Traditional Model. Second, the measurement noise in the Traditional Model is three times larger when compared to the corresponding original measurement noise. These disadvantages are eliminated in the UoC Model, which is described in the following section.

Furthermore, more than 30 minutes are usually required in the Traditional Model before a converged position solution can be obtained in post-processing static mode. The convergence of the ambiguity parameters as well as the position parameters is usually a function of the number of unknowns to be estimated and the combined level of the measurement noise and unmodelled residual errors. Given a specific amount of information, having fewer unknowns will result in the assignment of more information to them, therefore resulting in faster convergence. Similarly, a lower measurement noise level can bring about faster parameter convergence in the early stages of processing and more stable results thereafter.

To reduce the required convergence time, fewer unknowns and/or a lower measurement noise level are desired. Furthermore, observation models that allow for integer ambiguity resolution should be developed.

4.4.2. UoC Model

The UoC model is able to reduce the noise level and residual error. Furthermore, it also allows for the determination of integer ambiguities, decreasing the

number of unknowns. Code and phase observations used in this model are presented in Appendix B.

The UoC model forms ionosphere-free combinations that retain the integer nature of the ambiguities on both frequencies. Although not implemented in the current version of P^3, ambiguity resolution algorithms can be applied to resolve both L1 and L2 ambiguities, provided that the residual errors are sufficiently small. Furthermore, the combination of code and phase in the UoC model approximately halves the measurement noise.

4.5. Point Real-Time Kinematic Positioning

In this section, the concepts and challenges associated with Point Real-Time Kinematic Positioning (P-RTK) are described.

4.5.1. Concept

P-RTK is a new RTK positioning approach based on un-differenced carrier phase data using a single GPS receiver assisted by precise orbit and clock corrections. Since P-RTK has no requirement for the deployment of base station(s), it is a global RTK approach capable of providing greater solution consistency with increased operational flexibility. P-RTK will not only enrich the positioning aspect, but also provide better time transfer capabilities and aid meteorological disciplines.

4.5.2. Challenges

There are three major challenges associated with P-RTK: error mitigation, carrier phase ambiguity convergence, and ambiguity resolution.

ERROR MITIGATION

The ionosphere causes the largest absolute error in GPS observations. Due to its dispersive nature, signals from satellites suffer different delays on L1 and L2. As such, they can be mitigated through standard ionosphere-free code and carrier phase combinations. The troposphere cannot be mitigated in this manner due to its non-dispersive nature for GPS frequencies. However, it can be modeled or estimated along with other parameters.

Unconventional error sources must also be taken into consideration in order to implement a P-RTK system. Many of these errors have been ignored in the past because they are irrelevant, negligible, or are cancelled out through differencing. However, in the case of un-differenced code and carrier phase observations, some of these errors do not cancel out and their sizes are relatively large, influencing the accuracy of the method.

CARRIER PHASE AMBIGUITY CONVERGENCE

In most cases, carrier phase ambiguities are considered as float terms, often requiring long convergence times ranging from several tens of minutes to several hours. Since convergence is a crucial issue for real-time applications, long convergence times may prevent P-RTK from fulfilling the accuracy

requirements of some applications. As such, fast ambiguity convergence methods and algorithms should be developed.

AMBIGUITY RESOLUTION

Integer ambiguities must be resolved to fully realize the accuracy of carrier phase observations. If integer values of the carrier phase ambiguities can be determined on-the-fly over short time intervals, the P-RTK method will be able to support real-time kinematic positioning with centimetre level accuracy. Currently, this accuracy level is only feasible using double-differenced RTK systems.

Estimation of integer ambiguities is difficult due to the existence of non-zero initial phase offsets associated with the satellite and receiver oscillators and the level of residual errors that may exist in the system due to precise data, error modeling, and noise.

5. Quick Start Guide

This section is intended to quickly demonstrate the capabilities and features of the software without having to read all the details in the manual. In fact, simply running the program is probably the best way to learn the various features and functions that are available in P^3.

Great care was taken to ensure that P^3 would be user friendly and easy to operate. You will undoubtedly be familiar with most of the software and its features after having gone through this section.

5.1. Getting Data

This section describes where the necessary GPS data can be obtained for this tutorial section.

5.1.1. GPS Observation and Broadcast Ephemeris Data

Free GPS observation and broadcast ephemeris data is provided on the Scripps Orbit and Permanent Array Center (SOPAC) website provided below:

http://sopac.ucsd.edu

Click on the following links: Data Archive, SOPAC Data Browsers, and Data Archive: Data By Site. In the panel that appears, you should now be prompted to enter the start day, end day, as well as some information regarding the specific site for which you want to obtain data. Enter 209 for the start and end day (corresponding to July 28, 2003), and CRO1 for the 4-character site code. Make sure that 2003 is selected for both the start year and end year. Under Data Type select 'obs.' Once all the parameters are specified, click on Show Availability. A new panel should appear from which you should be able to download the observation file.

When the observation file (cro12090.03d.Z) has been downloaded, change the Data Type to 'nav' and download the broadcast navigation file (cro12090.03n.Z).

Once the observation and navigation files have been downloaded, unzip the files. You should now have two files: cro12090.03d and cro12090.03n.

Observation files available on SOPAC are in the Hatanaka (or compressed RINEX) file format. Click on hatanaka to obtain information about this format and to obtain the free conversion utility (CRX2RNX) for generating standard RINEX observation files. This information can also be accessed using the following address:

http://sopac.ucsd.edu/dataArchive/hatanaka.html

Note that a conversion is not necessary for the downloaded navigation file.

Approximate initial coordinates along with antenna parameters for the IGS station CRO1 are provided in Table 5.1 for July 28, 2003. Initial coordinates can be obtained from SOPAC using the following Internet address:

http://sopac.ucsd.edu/cgi-bin/sector.cgi

Table 5.1: Initial receiver coordinates and antenna parameters for CRO1.

X Coordinate (m)	2607771.2065
Y Coordinate (m)	-5488076.7241
Z Coordinate (m)	1932767.7632
Marker to ARP* (m)	0.0814
ARP to APC (m)**	0.0822
Antenna Height* (m)**	0.1636

* Marker to Antenna Reference Point (ARP) height offset is obtained from the RINEX observation file.

** ARP to Antenna Phase Center (APC) height offset can be obtained from the IGS Phase Center Variation (PCV) file, available on the following website:

http://igscb.jpl.nasa.gov/mail/igsmail/2000/msg00399.html

For the Turborogue AOAD/M_T antenna, the ARP to APC calculation is:

$$a_1(110mm) - a_2(128mm) = 0.0822m$$

$$a_1 = \frac{f_1^2}{f_1^2 - f_2^2} = 2.545$$

$$a_2 = \frac{f_2^2}{f_1^2 - f_2^2} = 1.545$$

*** The total antenna height (Marker to APC height offset) is computed by adding the Marker to ARP height offset and the ARP to APC height offset.

Refer to Section 8.2 for further details.

5.1.2. Precise Satellite Orbit and Clock Data

In this quick start example, we will perform processing in PPP mode. To do this, precise satellite orbit and clock data is necessary. For this example, data can be obtained from the IGS website, *http://igscb.jpl.nasa.gov*. To navigate to the required precise data, click on Data and Products, followed by Products available to download from this server.

The files previously obtained from SOPAC correspond to July 28, 2003. Precise data on the IGS website is organized by GPS week, which, for July 28, 2003, is 1229. Therefore, click on 1229, and download the compressed files ***igs12291.sp3.Z*** and ***igs12291.clk.Z***, corresponding to Monday of week 1229**.** After extraction, you will have two files: ***igs12291.sp3*** containing precise orbit data at a 15 minute interval, and ***igs12291.clk*** containing precise clock data at a 5 minute interval.

5.2. Entering Setup and Processing Parameters

Now that you have all of the necessary information for processing, you are ready to start entering parameters. First, you will need to specify the system mode. This is done by clicking on the *SYSTEM* button and selecting one of the options that appear in the drop-down menu. For this example, select post-mission. Next, click on the *SETUP* button. Here you will specify required parameters regardless of processing mode. In the **Setup** window that appears, under the *Settings* tab, enter the parameters listed in Table 5.2.

Table 5.2: Settings parameter values.

Parameter Name	Parameter Value
OBSERVATION INTERVAL (s)	1
GPS UTC OFFSET (s)	13
ELEVATION MASK (degrees)	10
GDOP MASK	20
CODE STD (m)	0.3
PHASE STD (m)	0.002
PHASE RATE STD (m/s)	0.002
LOG FILE PATH AND NAME	Specify path and name of LOG file.
OVERWRITE EXISTING FILE	Yes

Next, under the *Antenna* tab, enter the parameters listed in Table 5.3.

Table 5.3: Antenna parameter values.

Parameter Name	Parameter Value
MARKER TO ARP (EAST)	0.0
MARKER TO ARP (NORTH)	0.0
MARKER TO ARP (HEIGHT)	0.0814
GET FROM RINEX FILE	No
GET FROM PCV FILE	Yes
IGS PCV FILE*	Specify path and name of IGS PCV file.
VENDOR	TURBOROGUE
TYPE	AOAD/M_T

* IGS Phase Center Variation (PCV) file is available on the following website: *http://igscb.jpl.nasa.gov/mail/igsmail/2000/msg00399.html*

Next, under the *Initial Coordinate* tab, enter the parameters listed in Table 5.4.

Table 5.4: Initial Coordinate parameter values.

Parameter Name	Parameter Value
COORDINATE SYSTEM	Cartesian
DATUM*	WGS84
DATE OF COORDINATES (yyyy)	2003
DATE OF COORDINATES (mm)	07
DATE OF COORDINATES (dd)	28
X (m)	2607771.2065
Y (m)	-5488076.7241
Z (m)	1932767.7632

* Currently, WGS84 and ITRF00 are considered to be the same in the software. There are no published transformation parameters between the two.

Under the *Meteorology* tab, enter the values as shown in Table 5.5. These values will only be used to compute approximate values of the zenith tropospheric error in the first epoch. In subsequent epochs, the troposphere will be estimated as an unknown along with the three coordinate unknowns of the receiver and the receiver clock offset.

Table 5.5: Meteorology parameter values.

Parameter Name	Parameter Value
Temperature (degrees Celsius)	20
Pressure (mbar)	990
Humidity (%)	50

In this example we will not exclude any satellites. As such, all the checkboxes in the *Satellite Exclusion* tab should be blank.

Click on *OK* to retain the entered parameters in the *Setup, Antenna, Initial Coordinates, Meteorology,* and *Satellite Exclusion* tabs.

Now, you will specify the processing mode. Click on the *PROCESS* button and select PPP from the drop down menu. In the **PPP** window that appears, you will notice the parameters OBSERVATION FILE and BROADCAST EPHEMERIS FILE. Using the browse buttons to the right of the fields for these two parameters, locate the files that you have saved to your computer in Section 5.1.1. Select the file ***cro12090.03o*** for OBSERVATION FILE and the file ***cro12090.03n*** for BROADCAST EPHEMERIS FILE. Also, select the ***igs12291.sp3*** file for the PRECISE EPHEMERIS FILE parameter and ***igs12292.clk*** file for the PRECISE CLOCK FILE parameter. These latter two files have been obtained in Section 5.1.2. The values of the remaining parameters to be entered in the **PPP** window are listed in Table 5.6.

Table 5.6: PPP window parameter values.

Parameter Name	Parameter Value
ORBIT	SP3
CLOCK	5 Minutes
BACKWARD PROCESSING	Yes
TRADITIONAL MODEL	No
UoC MODEL	Yes
PHASE SMOOTHING	Yes
TROPOSPHERE	Yes
VELOCITY	No
STATIC	Yes
KINEMATIC	No

With these parameters, you will process the data in static mode, using the UoC Model. You will also apply phase smoothing of code as well as troposphere estimation.

Click on the FILTER SETTINGS button and specify the parameters as shown in Figure 5.1.

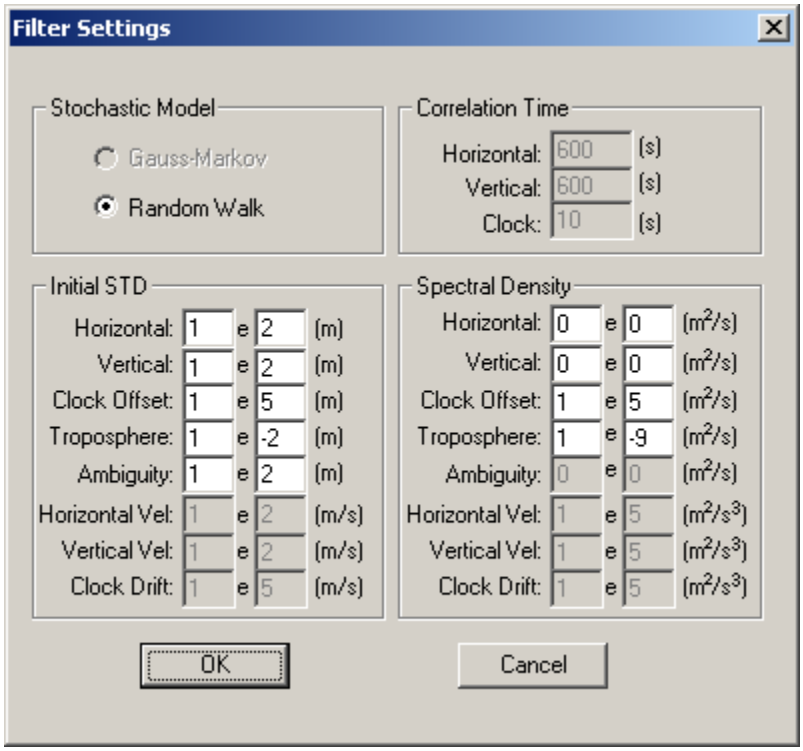


Figure 5.1: Filter Settings for static scenario.

5.3. Running P³

You are now ready to run the program. Click on the *RUN* button. As the program is running, you can view the various windows in the main screen that display pertinent information during processing, including a sky plot of the satellites, the computed solutions, and the residuals associated with the UoC model.

Program execution stops once all processing has been completed, or when the *STOP* button is pressed. When the program stops running, you can click on the *DISPLAY* button, which will allow you to view various graphs, including the position error, the receiver clock offset, the zenith tropospheric correction, and the number of satellites used in processing.

Other graphs can be selected from either the **DISPLAY** menu, or the menu that pops up when the right button on the mouse is pressed when the Display view has been activated. Other options, including STATISTIC and ALL RESULTS can also be accessed in this pop-up menu, called the **MOUSE** menu in the remainder of the manual. The **DISPLAY** and **MOUSE** menus are shown in Figure 5.2 on the following page.

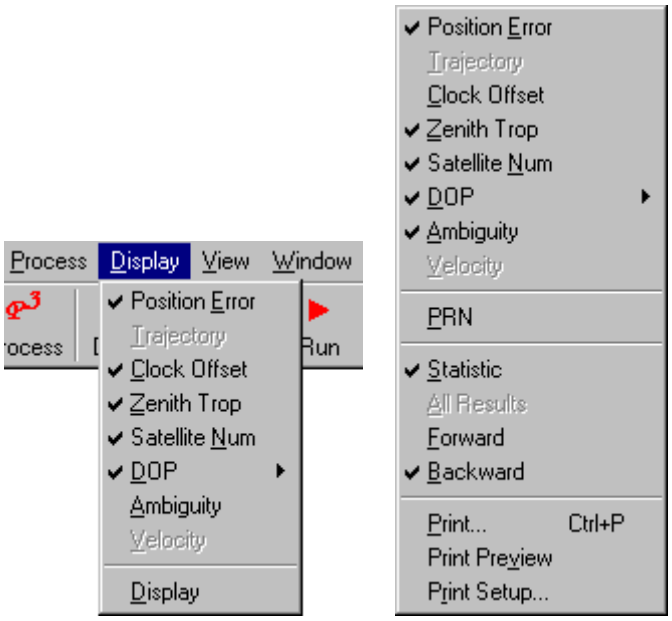


Figure 5.2: DISPLAY menu and **MOUSE** menu.

Experiment with the various options to see what can be done in the Display View. You will notice that some of the options included in the **MOUSE** menu are only applicable to specific graphs. Finally, you will note that the **MOUSE** menu contains options that allow you to print the Display View and its associated graphs.

6. Main Screen

The main screen of P^3 appears when the program is started. It is shown in Figure 6.1 below.

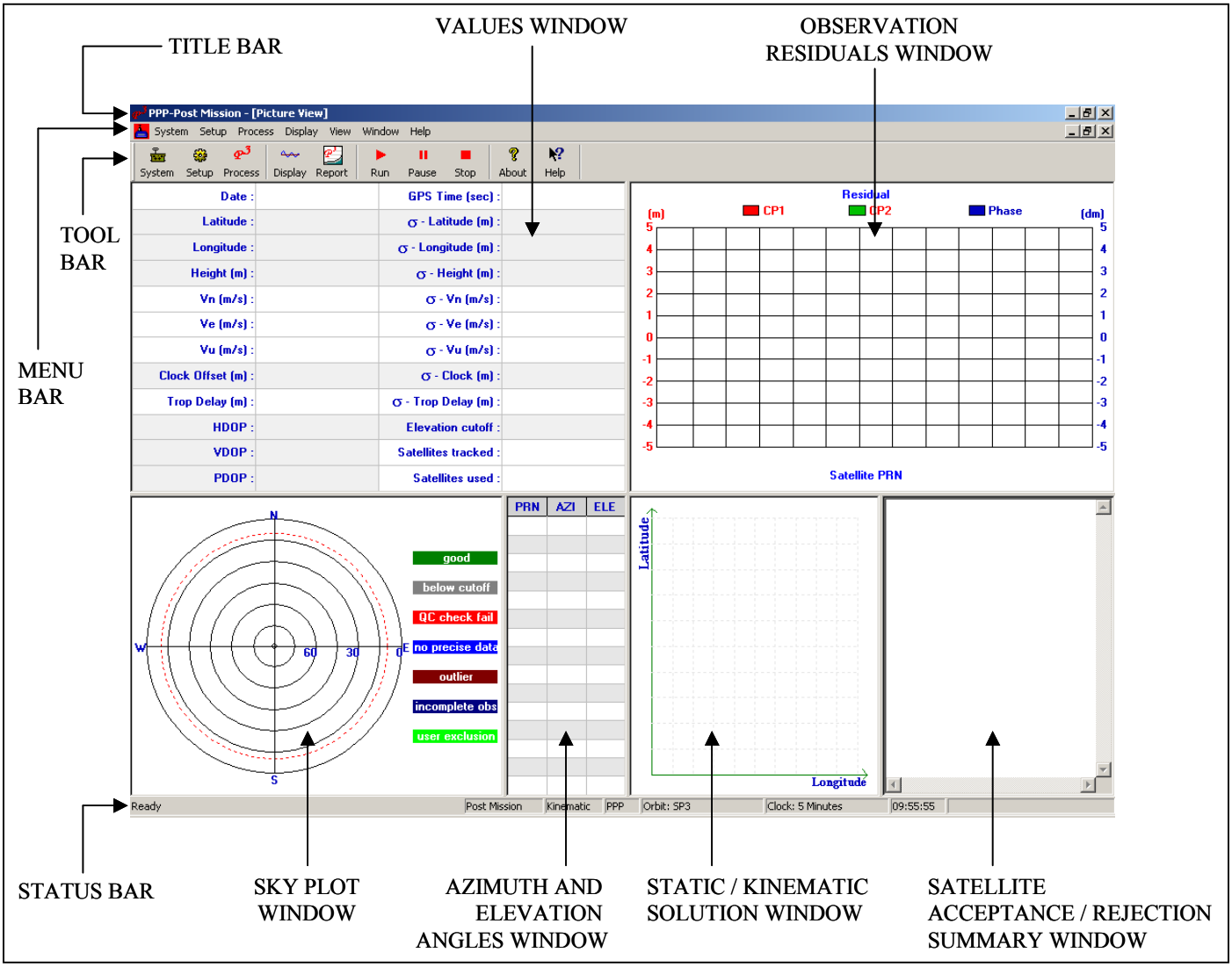


Figure 6.1: Main screen.

At the very top is the standard Title bar that appears with any application in Microsoft® Windows®. The Menu and Button bars are displayed below the Title bar, allowing access to the various features and functions provided in P^3. The Menu bar is described in Section 6.1.2, and the Button bar in Section 6.1.3. At the bottom of the screen is the Status bar, which displays some of the parameters chosen by the user, and is described in Section 6.1.4.

PICTURE VIEW

The remainder of the main screen is the 'Picture View', which displays information during data processing. The Picture View is subdivided into six windows, referred to as "processing windows." The information provided in each of these windows is described in Section 6.2. The Picture View can be closed at any time using the X mark in the right corner of the Menu bar. It can be opened again by selecting 'Pic View' from the **VIEW** menu. Processing does not require the Picture View to be open. It is important to note that processing is faster when the Picture View is either closed entirely or minimized.

RE-SIZING THE MAIN WINDOW

The bars that separate the various processing windows can be dragged to any position within the Picture View, changing the sizes and shapes of the individual processing windows.

6.1. P³ Bars

The Title, Menu, Button and Status bars are described in this section.

6.1.1. Title Bar

The Title bar, which appears at the top of most applications run in Microsoft® Windows®, is shown in Figure 6.1. A standard menu, undoubtedly familiar to Windows® users, appears when the user clicks on the icon on the very left of the Title bar. This menu is shown in Figure 6.2.

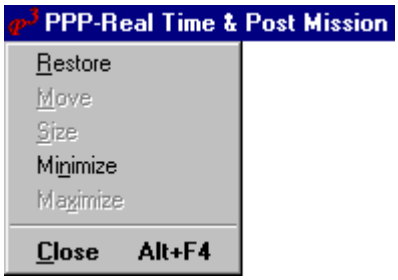


Figure 6.2: Title bar menu.

The usual options for changing the size of the P³ application window within the user's display or for closing the program are available in this menu. It is assumed that the user is familiar with these options, since they appear in virtually all applications that are run in Microsoft® Windows®.

6.1.2. Menu Bar

Each Menu bar option is shown in Figure 6.3 along with the corresponding menu. Most of the options available in the Menu bar are also available by clicking on the various buttons in the Button bar. A menu similar to the one shown in Figure 6.2 is opened when the user clicks on the red icon on the left of the Menu bar. Again, the options associated with it deal with changing the size of either the Picture View or the Display View within the P³ application, or closing them entirely.

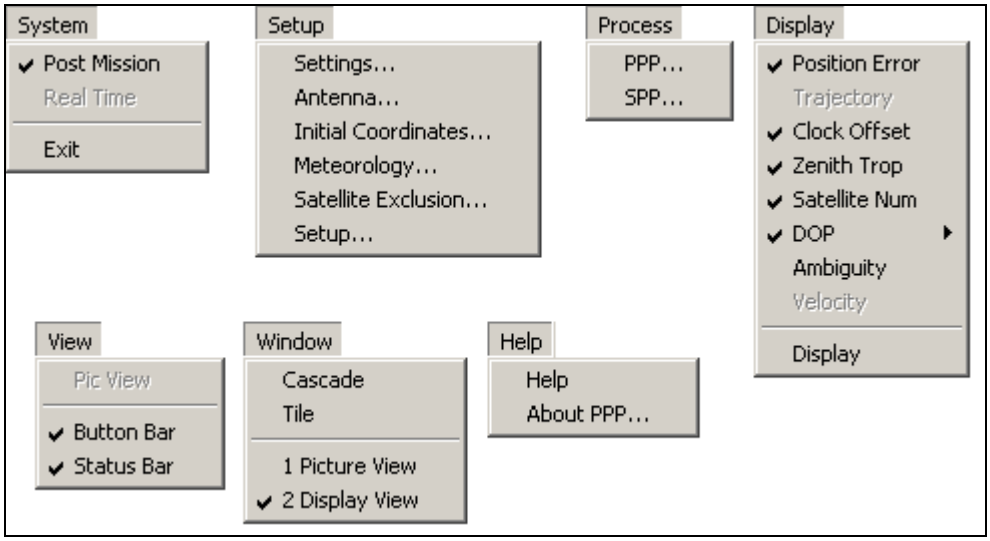


Figure 6.3: Menu bar options and their menus.

SYSTEM

The options associated with the **SYSTEM** menu are described in more detail in Section 7.

The Exit option allows the user to close the P^3 application. Note that when processing is taking place, a message will appear asking the user if they want to continue to close the application, or if they want to cancel and continue with processing. Choosing the cancel option does not close the application.

SETUP

The options associated with the **SETUP** menu are described in Section 8.

PROCESS

The options associated with the **PROCESS** menu are described in Section 9.

DISPLAY

The options associated with the **DISPLAY** menu are described in Section 14.

VIEW

The options in the **VIEW** menu allow the user to open the Picture View, which displays various quantities computed during processing, the sky plot, the position of satellites with respect to the receiver, the static or kinematic solution, accepted and rejected satellites, and the residuals associated with the current processing algorithm. The Picture View and these aspects are described in detail in Section 6.2.

The user can also toggle the Button bar (described in Section 6.1.3) and the Status Bar (described in Section 6.1.4). A checkmark will appear next to the Button bar or Status Bar options when they are enabled in the application.

WINDOW

Options in the **WINDOW** menu allow the user to arrange the two views that are available in P^3: Picture View and Display View. The Cascade and Tile options are available in many Windows® software packages, and therefore should be familiar to users.

The user can also select which view is currently active, simply by clicking on the view that they wish to activate. A checkmark will appear next to the active view. Note that in Figure 6.3, the Picture View and Display View are both open. As such, they both appear in the **WINDOW** menu. If only one of the views is open, the user will not be able to select which view is active. If both views are closed, the Cascade and Tile options will be disabled.

HELP

The Help option in the **HELP** menu opens this manual document. If this manual document does not exist in the same directory as the P^3 executable, the user will be prompted to find this document manually. The About PPP option shows the P^3 software logo, which is also shown on the title page of this manual.

6.1.3. Button Bar

The Button bar, shown in Figure 6.4, contains buttons that allow the user to specify various processing modes and parameters, and to control processing. Most of the information available by clicking the buttons in the Button bar is also available by accessing the various menu options in the Menu bar. The Menu bar is described in detail in Section 6.1.2.

Figure 6.4: Button bar.

SYSTEM

The *SYSTEM* button and its associated options are described in Section 7.

SETUP

The *SETUP* button and its associated options are described in Section 8.

PROCESS

The *PROCESS* button and its associated options are described in Section 9.

DISPLAY

The *DISPLAY* button and its associated options are described in Section 14.

REPORT

The *REPORT* button and its associated options are described in Section 13.

RUN, PAUSE, STOP

The *RUN, PAUSE,* and *STOP* buttons are described in Section 11.

ABOUT

The *ABOUT* button shows the P[3] software logo, which is also shown on the title page of this manual.

HELP

The *HELP* button in the Tool Bar opens this manual document. If this manual document does not exist in the same directory as the P[3] executable, the user will be prompted to find this document manually.

6.1.4. Status Bar

The Status bar, shown in Figure 6.5, contains information regarding the status of the program. As can be seen, the Status bar indicates the system mode (real-time or post-mission), and the processing modes (static or kinematic, and SPP or PPP). Finally, the Status bar also contains information as to what is being used for satellite orbits and clocks. Computer time is included afterwards, which switches to the GPS time of the current epoch during processing.

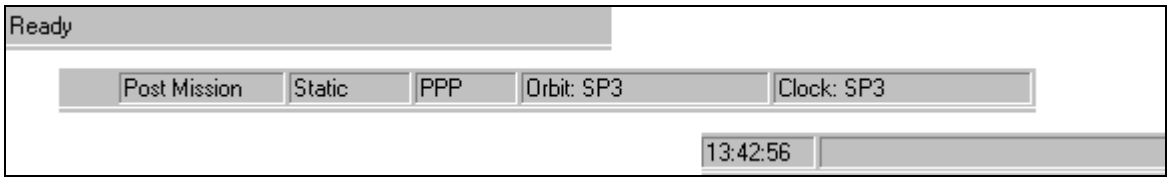


Figure 6.5: Status bar.

6.2. P[3] Processing Windows

This section describes the six processing windows within the Picture View that appear when P[3] is opened. These windows are:

- Values Window
- Sky Plot Window
- Azimuth and Elevation Angles Window
- Static/Kinematic Solution Window
- Satellite Acceptance/Rejection Summary Window
- Observation Residuals Window

Each of these is described in the following sections.

6.2.1. Values Window

The upper left portion of the screen, shown in Figure 6.6, displays current values of various parameters based on the current processing epoch.

Date :	2003-02-15	GPS Time (sec) :	519810.0
Latitude :	45° 57' 20.8827"	σ - Latitude (m) :	0.145
Longitude :	-78° 4' 16.9363"	σ - Longitude (m) :	0.137
Height (m) :	200.786	σ - Height (m) :	0.234
Vn (m/s) :	0.000	σ - Vn (m/s) :	0.000
Ve (m/s) :	0.000	σ - Ve (m/s) :	0.000
Vu (m/s) :	0.000	σ - Vu (m/s) :	0.000
Clock Offset (m) :	-231.505	σ - Clock (m) :	4.310
Trop Delay (m) :	2.291	σ - Trop Delay (m) :	0.000
HDOP :	1.179	Elevation cutoff :	10°
VDOP :	1.938	Satellites tracked :	9
PDOP :	2.268	Satellites used :	7

Figure 6.6: Values Window during processing.

The parameters are listed in Table 6.1, along with their units and a short description of each. Note that all values that appear in the Values Window are for the current processing epoch.

Table 6.1: Values Window parameter descriptions.

Parameter	Description
Date (yyyy-mm-dd)	The date of the data.
Latitude (DMS)	Latitude of GPS receiver (in NAD83 when GPS*C orbits and clocks are used, otherwise in WGS84).
Longitude (DMS)	Longitude of GPS receiver (in NAD83 when GPS*C orbits and clocks are used, otherwise in WGS84).
Height (m)	Height of GPS receiver (in NAD83 when GPS*C orbits and clocks are used, otherwise in WGS84).
Vn (m/s)	Velocity of the GPS receiver in the northing direction, optionally computed in PPP mode in the presence of Doppler observations.
Ve (m/s)	Velocity of the GPS receiver in the easting direction, optionally computed in PPP mode in the presence of Doppler observations.
Vu (m/s)	Velocity of the GPS receiver in the zenith direction, optionally computed in PPP mode in the presence of Doppler observations.

Clock Offset (m)	Receiver clock offset.
Trop Delay (m)	Either the modelled or estimated tropospheric delay, based on the user's choice.
HDOP	Horizontal Dilution of Precision, indicating the strength of satellite geometry in the horizontal plane of the receiver.
VDOP	Vertical Dilution of Precision, indicating the strength of satellite geometry in the receiver's zenith direction.
PDOP	Position Dilution of Precision, indicating the strength of satellite geometry in all three coordinate directions.
GPS Time (s)	GPS time of the current processing epoch.
σ **- Latitude (m)**	Latitude standard deviation, computed from the Variance-Covariance matrix of the parameters.
σ **- Longitude (m)**	Longitude standard deviation, computed from the Variance-Covariance matrix of the parameters.
σ **- Height (m)**	Height standard deviation, computed from the Variance-Covariance matrix of the parameters.
σ **-Vn (m/s)**	Standard deviation of northing velocity, optionally displayed in PPP mode in the presence of Doppler observations.
σ **-Ve (m/s)**	Standard deviation of easting velocity, optionally displayed in PPP mode in the presence of Doppler observations.
σ **-Vu (m/s)**	Standard deviation of zenith velocity, optionally displayed in PPP mode in the presence of Doppler observations.
σ **-Clock (m)**	Standard deviation of receiver clock, computed from the Variance-Covariance matrix of the parameters.
σ **- Trop Delay (m)**	The tropospheric delay standard deviation, as obtained from the Variance-Covariance matrix of the parameters. This value is computed only when the user selects troposphere estimation. When the troposphere is modelled, the standard deviation is zero.
Elevation Cutoff (degrees)	User specified elevation angle cutoff. All satellites with an elevation angle less than the specified value will not be used in computations.
Satellites tracked	The number of satellites above the receiver's horizon that are being observed.

Satellites used	The number of satellites above the receiver's horizon that are being used in the solution computation.

6.2.2. Sky Plot Window

The lower left portion of the screen displays the Sky Plot Window, which shows a sky plot of all satellites above the receiver's horizon, as shown in Figure 6.7.

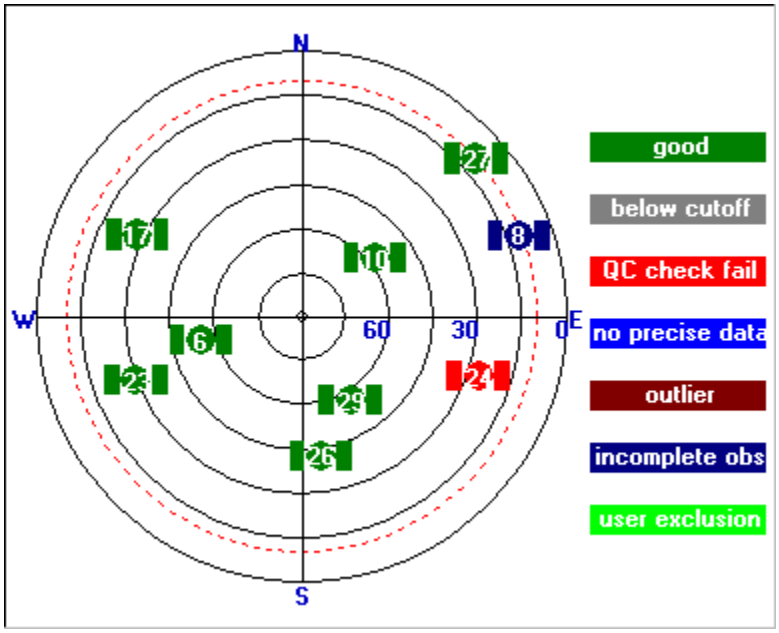


Figure 6.7: Sky Plot Window during processing.

SKY PLOT CENTER

The sky plot is centred at the receiver's approximate position, which is entered by the user prior to processing in the *Initial Coordinates* tab of the **Setup** window (see Section 8.3). North, south, east and west directions are labelled. Using broadcast satellite coordinates, which may or may not be corrected by precise satellite orbit data, as well as the approximate position of the GPS receiver, azimuth and elevation angles are computed for each satellite.

SKY PLOT CIRCLES

The outside concentric circle of the sky plot corresponds to an elevation angle of zero degrees. Each concentric circle towards the centre of the sky plot indicates a 15° increase in the elevation angle, up to a maximum of 90°, which coincides with the centre of the figure.

SATELLITE COLOUR CODINGS

All satellites are colour-coded based on the legend that appears on the right of the sky plot. Furthermore, each satellite is labelled with its corresponding PRN, which appears in the centre. The possible satellite colours as well as a description of each colour are provided in Table 6.2. A satellite is only used in computations if its status is 'good.'

Table 6.2: Description of satellite status colours.

Status	Description
good	Satellite data is good, and, if enough satellites are available, is used in the processing computations.
below cutoff	Elevation angle of the satellite is below the elevation cutoff angle specified by the user.
QC check fail	Satellite failed residual check.
no precise data	Precise data was not available for the specific processing epoch, or the clock or orbit corrections are too old.
outlier	Current satellite observation is unacceptable.
incomplete obs	This occurs when one or more observations are not available for the current processing epoch. For example, in SPP mode, which uses L1 & L2 code, the satellite is said to have an incomplete set of observations if one of these observations is missing.
user exclusion	A satellite with this colour is not used in computations because the user has chosen to exclude it.

6.2.3. Azimuth and Elevation Angles Window

To the right of the panel containing the sky plot and its associated legend, the computed azimuth and elevation angles are tabulated for all satellites above the receiver's horizon, regardless of their current status.

The PRN within each satellite in the sky plot can be linked to the PRN in this table. Figure 6.8 shows an example of this window.

PRN	AZI	ELE
6	256.0	55.2
27	48.1	10.3
29	149.4	56.7
8	69.8	11.2
24	108.7	26.4
17	296.4	28.5
26	171.8	42.3
23	248.7	30.1
10	52.5	58.3

Figure 6.8: Azimuth and Elevation Angles Window during processing.

6.2.4. Static/Kinematic Solution Window

To the right of the window containing the azimuth and elevation angle values is a window containing the computed solutions for each processed epoch. Figure 6.9 shows the solution in static mode on the left, and the solution trajectory in kinematic mode on the right.

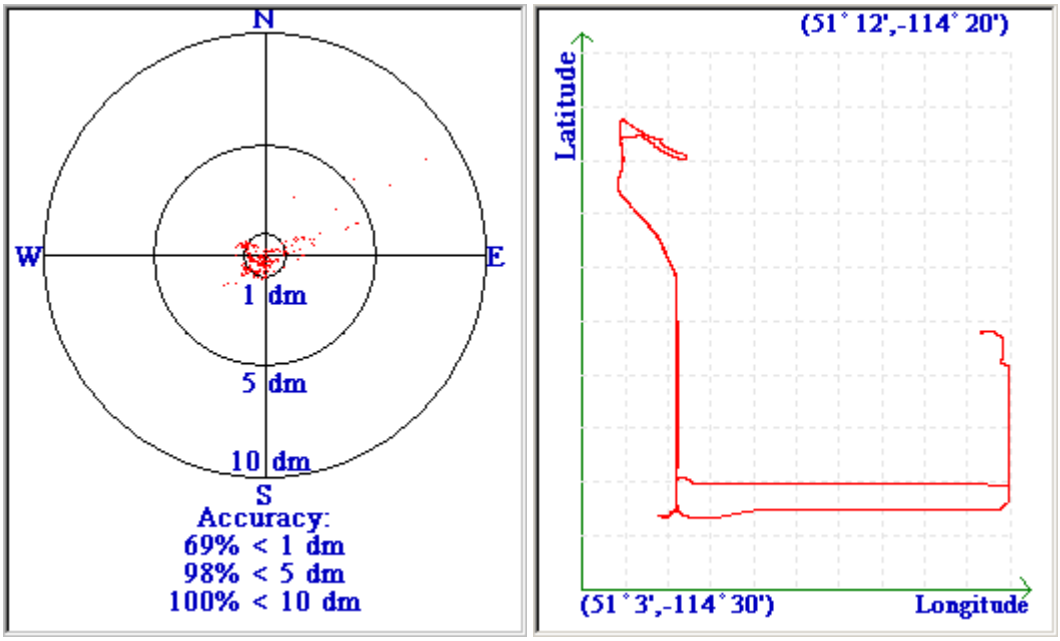


Figure 6.9: Static and Kinematic Solution Windows during processing.

STATIC SOLUTION WINDOW

In static mode, the solutions generated at each epoch appear as red dots. The centre point of the plot is located at the initial coordinates specified by the user in the *Initial Coordinates* tab of the **Setup** window (see Section 8.3). As such, the user should not be too concerned if the computed solutions are not exactly at the centre of the static solution plot since this would only occur if the specified initial coordinates were very accurate.

SPACING OF CONCENTRIC CIRCLES

The above Static Solution Window has been run in PPP mode. As such, the concentric circles are 1 dm, 5 dm and 10 dm away from the centre point. In SPP mode, due to the poorer attainable accuracy, the circles are 1 m, 5 m and 10 m away from the centre point.

ACCURACY STATISTICS

The Static Solution Window also shows 'accuracy' statistics. These simply show the percentage of solutions that fall within each of the concentric circles. For example, in Figure 6.9 above, 69 % of the solutions are located in the circle 1 dm away from the centre point, 98 % in the circle 5 dm away, and 100 % in the outer circle 10 dm away.

KINEMATIC SOLUTION WINDOW

The Kinematic Solution Window, shown on the right in Figure 6.9, displays a trajectory of the solution as processing takes place. The horizontal axis displays the longitude, and the vertical axis displays the latitude. Coordinates of the lower left and upper right corners of the grid are provided, in degree-minute-second (DMS) format. The first DMS value in each of the brackets is latitude, the second longitude. The Kinematic Solution Window adjusts as processing is taking place so that the entire trajectory is always contained in the window.

OPENING / CLOSING PICTURE VIEW DURING PROCESSING

Note that when the Picture View is re-opened when processing is taking place, no past processing information will be displayed in the Static/Kinematic Solution Window. The display of the red dots, indicating the position of static solutions, or the display of the kinematic solution trajectory, only occurs when the Picture View is open.

Note also that processing is faster when the Picture View is not completely open. To process results faster, the user can either minimize the Picture View, or close it completely.

6.2.5. Satellite Acceptance/Rejection Summary Window

The panel on the very right in the lower portion of the Picture View summarizes the results of the computation of the receiver's position. It also contains a list of all accepted and rejected satellites, as shown in Figure 6.10.

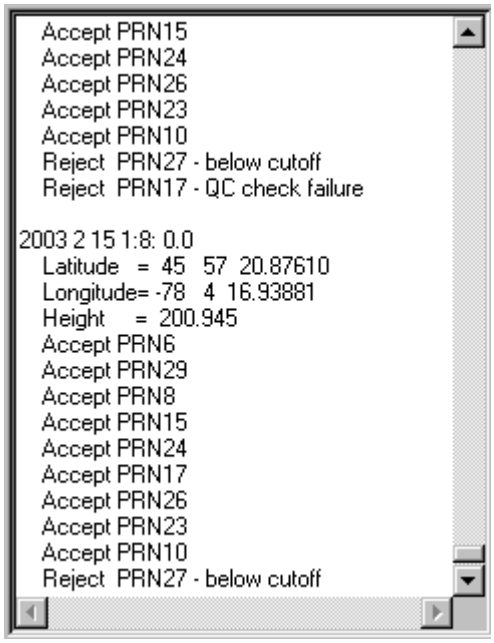


Figure 6.10: Satellite Acceptance/Rejection Summary Window during processing.

The purpose of this window is to show some processing results at each epoch. A more comprehensive processing summary for each epoch is output to the LOG file (see Section 12) for each epoch at which a solution has been computed.

CASES WHERE A SOLUTION IS NOT COMPUTED

At times, a solution is not computed at a particular epoch. This may occur because of the following reasons:

- not enough satellites – not enough satellites were available for computations
- couldn't converge – solution did not converge
- matrix is singular – a singular matrix was encountered in the computations
- above GDOP threshold – the GDOP MASK parameter specified by the user in the *Settings* tab in the **Setup** window was exceeded
- residual check fail – a check of the residuals associated with the current processing model caused the computation of the position to be rejected

No data is output to the LOG file at an epoch for which a solution was not computed.

POSITION COMPUTATION

At each observation epoch, the date and time appear, in yyyy-mm-dd and hh:mm:ss.s formats, respectively. Note that the time is UTC as it exists in the observation file. The computed latitude, longitude and height of the receiver follow. The coordinates of the receiver are the same as the ones that are listed in the upper left portion of the Picture View in the Values Window, which was described in Section 6.2.1.

SATELLITE LISTING AND THEIR STATUS

All satellites above the receiver's horizon are listed, and are either accepted or rejected. If they are accepted, then they will also appear green in the Sky Plot Window, since their status must be 'good' in order for them to be used in the computations. All satellites with other colour codings in the Sky Plot Window will be rejected in this summary window, and a short phrase will appear explaining the cause of the rejection. This phrase will match the phrases that appear in the legend of the Sky Plot Window.

6.2.6. Observation Residuals Window

The upper right portion of the main screen displays the observation residuals for satellites used in the least-squares computation. A sample Observation Residuals Window is shown in Figure 6.11.

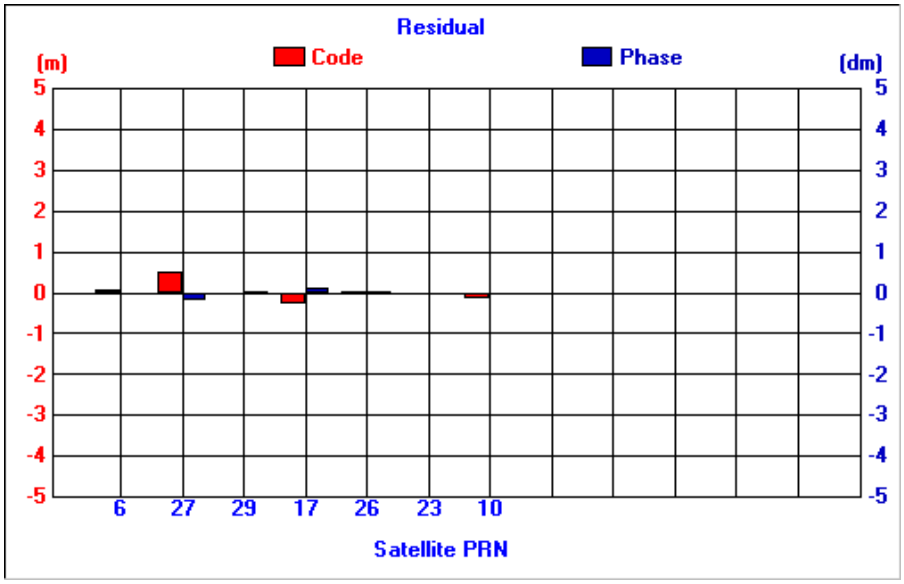


Figure 6.11: Observation Residuals Window during processing.

HORIZONTAL AND VERTICAL AXES

The PRN of each satellite whose status is 'good' at the current processing epoch appears on the horizontal axis. Based on the processing mode specified by the user, this plot may display the residuals associated with various ionospheric-free code and phase combinations. At each PRN listed on the horizontal axis, all the residual types associated with the current processing mode will be plotted as vertical bars. They will be colour-coded according to the legend that appears near the top of the window, as shown in Figure 6.11.

RESIDUAL TYPES BASED ON PROCESSING MODE

The vertical axis on the left is to be used with the 'Code' residual types, and is in metres. The axis on the right is to be used with 'Phase', 'CP1' and 'CP2' residual types, and is in decimetres. Table 6.3 below lists the various residual types that may appear in the Observation Residuals Window. A description of these residual types is provided, along with the corresponding processing mode in which these residual types appear.

Table 6.3: Residual types and their processing modes.

Residual Types	Description	Processing Mode
Code	**L1 C/A code.** Ionospheric parameters will be taken from the navigation file if available.	**SPP** L1 ONLY selected under Observables in the **SPP** window.

Code	**L1 & L2 ionospheric-free code combination.**	**SPP** L1 & L2 selected under Observables in the **SPP** window.
Code **Phase**	**Traditional L1 & L2 ionospheric-free code combination.** **Traditional L1 & L2 ionospheric-free phase combination.**	**PPP** TRADITIONAL MODEL selected under Model in the **PPP** window.
CP1 **CP2** **Phase**	**UoC L1 code and phase ionospheric-free combination** **UoC L2 code and phase ionospheric-free combination** **Traditional L1 & L2 ionospheric-free phase combination.**	**PPP** UoC selected under Model in the **PPP** window.

SPP and PPP processing modes are described in more detail in Section 9 along with the various windows where the parameters mentioned in Table 6.3 are specified. The various ionospheric-free code and phase combinations are provided in Appendix B. However, knowledge of these observables is not necessary to operate the software.

6.3. Processing Progress Bar

During processing, a progress bar appears in the Button bar to the right of the Help button. It is shown in Figure 6.12.

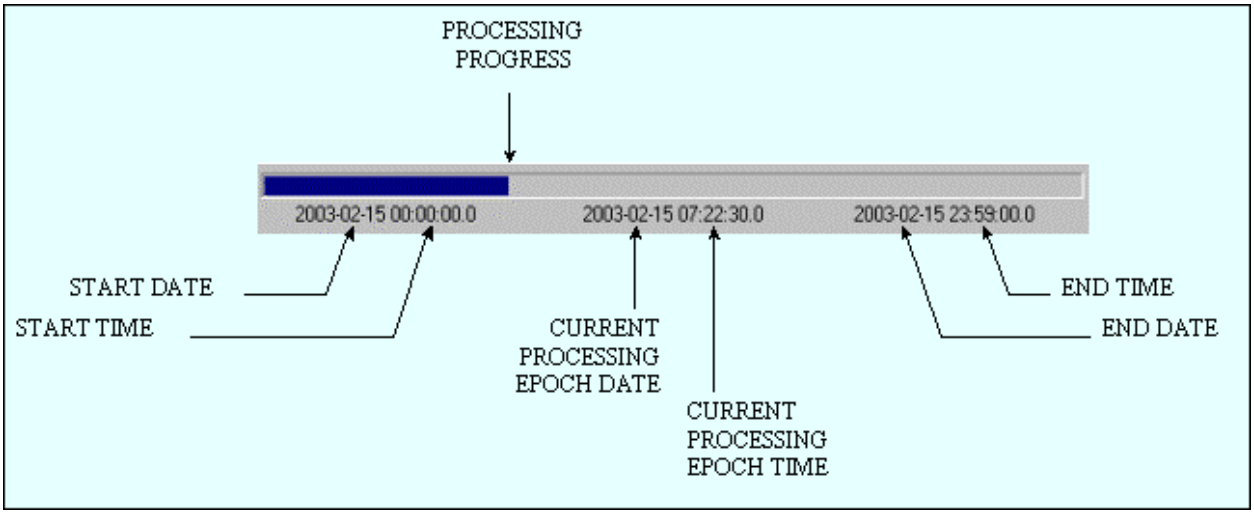


Figure 6.12: Processing Progress bar.

On the left side, the starting date and UTC time of the GPS data contained in the observation file are shown. On the right side of the Processing Progress Bar, the ending date and UTC time are shown. Finally, in the middle of the bar, the date and UTC time of the current epoch being processed are shown. As can be seen in Figure 6.12, dates are in yyyy-mm-dd format, and times are in hh:mm:ss.s format.

FORWARD PROCESSING

During forward processing, the blue bar moves from left to right until all forward processing has been completed. All processing comes to a halt once the last epoch in the observation file has been processed.

BACKWARD PROCESSING

If the user has selected BACKWARD PROCESSING in post-mission PPP mode (see Section 10.7), processing will continue backwards after forward processing is completed. The blue bar in the Processing Progress Bar will move from right to left.

7. System Modes

This section describes the two available system modes: post-mission processing and real-time processing. The user can toggle between the two system modes by clicking the *SYSTEM* button and selecting the processing mode from the drop down list. The choice between the two is also available from the menu, by clicking on **SYSTEM**.

This version of P^3 only implements post-mission processing. Although real-time processing has been developed and its functions have been described in the manual, it is available only as an option and is disabled in the current version. Reasons for this can be found under the 'Real-Time Corrections' heading below. For users who are interested in the real-time processing functions of P^3, please contact Dr. Yang Gao, Department of Geomatics Engineering, The University of Calgary, 2500 University Drive, NW, Calgary, Alberta, Canada T2N 1N4, gao@geomatics.ucalgary.ca.

7.1. Post-Mission Processing

Post-mission processing refers to data processing that is done after all the data has been collected. Post-mission processing in SPP mode is described in Section 9.1.1, and post-mission processing in PPP mode in Section 9.2.1.

7.2. Real-Time Processing

Real-time processing refers to data processing that occurs in real-time as data is collected. Parameter estimation is done immediately after a particular epoch of data has been obtained. Real-time processing in SPP mode is described in Section 9.1.2, and real-time processing in PPP mode in Section 9.2.2.

Real-time processing in PPP mode requires the application of real-time GPS corrections to the broadcast orbit and clock data in order to achieve high accuracy. Information about real-time correction services is provided under the 'Real-Time Corrections' heading in the Introduction (Section 1).

8. Setup Parameters

Regardless of the processing mode, certain parameters must be specified. The *SETUP* button in the Button bar, or the Setup option in the **SETUP** menu, both activate the same window, which contains the following tabs:

- *Settings*
- *Antenna*
- *Initial Coordinates*
- *Meteorology*
- *Satellite Exclusion*

Note that each of the above tabs can be opened independently of the others using the **SETUP** menu, and selecting Settings, Antenna, Initial Coordinates, Meteorology, or Satellite Exclusion. Each of these tabs is shown below, and a description of each is provided.

8.1. Settings

The *Settings* tab is shown in Figure 8.1. The four subsets within this tab, namely 'Constants', 'Mask', 'Observables STD' and 'Log File Path and Name' are described in Sections 8.1.1 to 8.1.4.

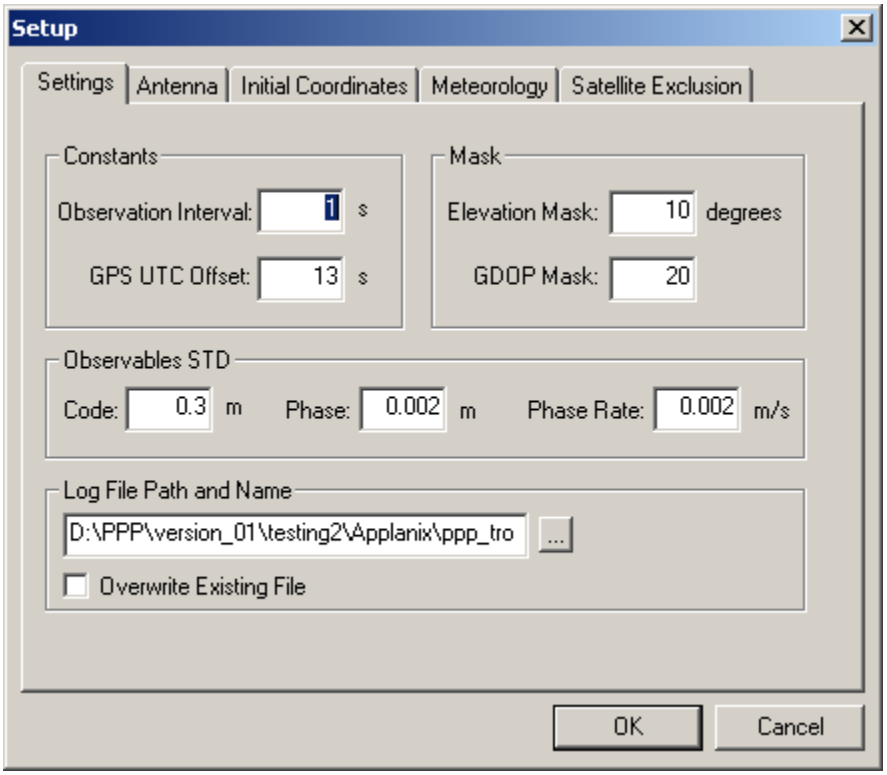


Figure 8.1: *Settings* tab in **Setup** window.

8.1.1. Constants

Two constants need to be specified: OBSERVATION INTERVAL and GPS UTC OFFSET.

OBSERVATION INTERVAL

The OBSERVATION INTERVAL is the time interval between consecutive epochs in the RINEX observation file.

GPS UTC OFFSET

The GPS UTC OFFSET refers to the current number of leap seconds between GPS and UTC.

UTC was introduced in 1972. Its purpose is to provide a highly uniform time unit as well as the best possible adaptation to UT1, which corresponds to the Earth's rotation. Because UT1 changes due to irregularities in the Earth's rotation, the addition of leap seconds to UTC is required so that it is close to UT1. This introduces an offset with respect to GPS time, which is a constant time scale.

8.1.2. Mask

Two masking parameters may be specified in this panel: ELEVATION MASK and GDOP MASK.

ELEVATION MASK

The ELEVATION MASK parameter, in degrees, specifies the elevation cutoff angle. Satellites in the receiver's horizon plane with an elevation angle lower than the ELEVATION MASK parameter will not be used in processing.

GDOP MASK

The GDOP MASK parameter imposes a threshold value for the Geometric Dilution of Precision (GDOP). When the GDOP is greater than the value specified, then no computation is performed for the current epoch.

8.1.3. Observables STD

This portion of the *Settings* tab allows users to specify the measurement standard deviation values for the CODE, PHASE and PHASE RATE parameters. Calculations of default values that should be used are shown in Table 8.1.

Table 8.1: Computation of standard deviations.

Parameter	Standard Deviation
Code STD	1 % of P code chip wavelength = 0.01 x 30 m = **0.3 m**
Phase STD	1 % of L1 cycle = 0.01 x 0.19 m = 0.0019 m ~ **0.002 m**
Phase Rate STD	1 % of L1 cycle = 0.01 x 0.19 m = 0.0019 m ~ **0.002 m**

STD ASSOCIATED WITH IONOSPHERIC-FREE COMBINATIONS

Several code and phase combinations are implemented based on the processing mode selected by the user in order to create ionospheric-free observables. These new observables change the standard deviations in Table 8.1, because the standard deviations listed in this table are for individual code, phase, or phase rate measurements only. However, the user should not have to modify the values listed above to account for these new ionospheric-free combinations since this is done internally in the software.

8.1.4. Log File Path and Name

Type in the path and name of the P^3 LOG file (described in Section 12) that will be output during processing. Optionally, use the browse button to select the folder where the file will be stored.

OVERWRITE EXISTING FILE

The OVERWRITE EXISTING FILE option can be used to automatically overwrite the P^3 LOG file if it already exists. This option has been implemented so that the user will not accidentally overwrite an existing file with new logging information.

When this option is left unchecked and the file that is specified in the 'Log File Path and Name' panel already exists, a message will appear asking the user if they want to overwrite the existing file. At that time, the user can click YES, and the file will be overwritten with logging information for the current processing session. If the user clicks NO, a dialog will appear allowing the user to specify an alternate path and name for the file.

Alternatively, if the OVERWRITE EXISTING FILE option is checked and the file that is specified in the 'Log File Path and Name' panel already exists, the existing file will be overwritten with logging information for the current processing session without alerting the user that the file already exists.

OK

Once all of the parameters have been specified and other parameters in the **Setup** window do not need to be changed, click on *OK* to exit and retain your parameter input. If the parameters in any of the other tabs need to be modified, simply click on the tabs and modify the parameters.

CANCEL

If you would like to close the window without saving the parameters that were specified, simply click on the *CANCEL* button or on the X in the top right corner of the window and your changes will not be retained. Note that the *CANCEL* button applies to all tabs in the **Setup** window. As such, changes to any parameters in any of the other tabs will not be retained when the *CANCEL* button is pressed.

8.2. Antenna

The *Antenna* tab is shown in Figure 8.2. The three subsets within this tab, namely 'Marker to ARP', 'ARP to APC' and 'PCV File' are described in Sections 8.2.1 to 8.2.3.

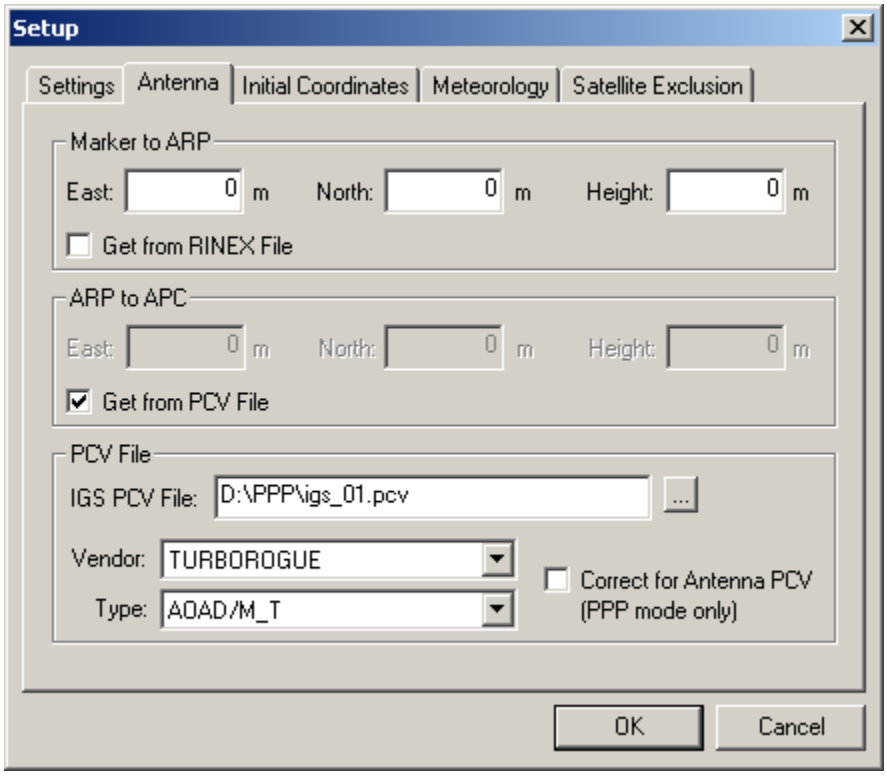


Figure 8.2: *Antenna* tab in **Setup** window.

8.2.1. Marker to ARP

In this portion of the *Antenna* tab, the easting, northing and height components of the Marker to Antenna Reference Point (ARP) vector can be specified. The Marker refers to the point whose coordinates the user wants to determine. The ARP is the physical point on the antenna whose coordinates will be determined if the Marker to ARP vector is not taken into consideration. Note that the Marker to ARP vector is usually a vertical offset that does not include easting and northing components. A measurement with a ruler or tape measure is usually sufficient for determining the Marker to ARP offset during data

collection provided that the user knows where the ARP is located on the antenna.

GET FROM RINEX FILE

This option automatically extracts the Marker to ARP offset from the RINEX observation file that is specified in post-mission in either SPP or PPP mode. However, the user should be aware that although the `ANTENNA: DELTA H/E/N` parameter is required in all RINEX observation files (from which the Marker to ARP offset is obtained), the three components may not always be correctly specified in the RINEX file. This is because the GPS receiver that collects data has no way of measuring the Marker to ARP vector by itself – this information is input by the user at the time of data collection.

For example, if the user inputs zero for all three components during data collection, but measures the height offset of the ARP with respect to the Marker as 17 cm, incorrect results (offset by 17 cm) will be obtained if the user relies on the information contained in the RINEX observation file.

8.2.2. ARP to APC

In this panel, the user can specify the easting, northing and height components of the ARP to Antenna Phase Centre (APC) offset. Unlike the Marker to ARP offset, this offset cannot be measured with either a ruler or tape measure because the APC is not a physical point on the antenna that can be identified. The calculation of this offset is provided below.

GET FROM PCV FILE

If the components of the ARP to APC vector are unknown, they can be calculated automatically based on values contained in the IGS Phase Center Variation (PCV) file (igs_01.pcv), which is available on the following website:

http://igscb.jpl.nasa.gov/mail/igsmail/2000/msg00399.html

If the link has expired, typing "igs_01.pcv" in any browser should bring up a list of websites from which this file can be obtained. Selecting the GET FROM PCV FILE option disables the three boxes for manual entry of the ARP to APC components, and enables the PCV File panel, described in Section 8.2.3 below.

CALCULATING ARP TO APC OFFSETS MANUALLY

The ARP to APC calculation is as follows:

$$ARPtoAPC = \frac{f_1^2}{f_1^2 - f_2^2} H_1 - \frac{f_2^2}{f_1^2 - f_2^2} H_2 \qquad (8.1)$$

Where:

H_1 – height offset on L1 frequency (from igs_01.pcv file)
H_2 – height offset on L2 frequency (from igs_01.pcv file)
f_1 – L1 signal frequency (1575.42 MHz)
f_2 – L2 signal frequency (1227.60 MHz)

EXAMPLE

For the Turborogue AOAD / M_T antenna, the antenna phase center offset parameters as well as the phase center variation values, as they appear in the igs_01.pcv file, are shown in Figure 8.3.

```
TURBOROGUE      AOAD/M_T                                                ( 0) 96/06/30
       0.0       0.0     110.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
       0.0       0.0     128.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

Figure 8.3: Parameters associated with TURBOROGUE AOAD / M_T antenna.

The antenna phase center offsets for the L1 signal for north, east and up, are 0.0, 0.0 and 110.0, respectively. Similarly, the offsets for the L2 signal are 0.0, 0.0 and 128.0. Descriptions of these values are provided in the header of the file. All values are reported in millimetres.

The ARP to APC calculation for the height offset is:

$$ARPtoAPC = 2.5457(0.1100m) - 1.5457(0.1280m) = 0.08218m \qquad (8.2)$$

If non-zero values exist for the north and east components of the ARP to APC offset, this calculation has to be performed for those components as well.

8.2.3. PCV File

In this panel, the IGS PCV file can be specified along with the antenna vendor and antenna type. This information will be used to automatically calculate the ARP to APC offset. These options can only be enabled when the GET FROM PCV FILE option is selected in the 'ARP to APC' panel described in Section 8.2.2.

IGS PCV FILE

Type in the path and name of the IGS PCV file. Optionally, use the browse button to specify the path and name of the IGS PCV file. If you do not have this file, use the Internet address provided in Section 8.2.2.

VENDOR

This parameter allows users to select the vendor of the antenna that was used for data collection. First specify the antenna vendor, and then specify the antenna type.

TYPE

This parameter allows users to select the type of antenna that was used for data collection. Specify the antenna vendor first, and then specify the antenna type.

Note that the lists of antenna vendors and types are obtained from the IGS PCV file. It is possible that a particular antenna will not be listed in this file.

CORRECT FOR ANTENNA PCV

This option, available in PPP mode only, can be selected to correct the measurements for the effect of Phase Center Variation (PCV). This option is only available when the user selects GET FROM PCV FILE in the 'ARP to APC' panel. If the user chooses to enter the components of the ARP to APC offset manually, the correction for antenna PCV is not available.

Note that the correction for antenna PCV is currently not available in this version of P^3.

OK

Once all of the parameters have been specified and other parameters in the **Setup** window do not need to be changed, click on *OK* to exit and retain your parameter input. If the parameters in any of the other tabs need to be modified, simply click on the tabs and modify the parameters.

CANCEL

If you would like to close the window without saving the parameters that were specified, simply click on the *CANCEL* button or on the X in the top right corner of the window and your changes will not be retained. Note that the *CANCEL* button applies to all tabs in the **Setup** window. As such, changes to any parameters in any of the other tabs will not be retained when the *CANCEL* button is pressed.

8.3. Initial Coordinates

This part of the **Setup** window requires the user to enter approximate coordinates for the initial position of the receiver.

COORDINATE SYSTEM

First, specify the coordinate system from the COORDINATE SYSTEM drop down box. The *Initial Coordinate* tab within the **Setup** window is shown in Figure 8.4 when Cartesian coordinates are specified for the COORDINATE SYSTEM parameter. Figure 8.5 shows the corresponding window when Ellipsoidal coordinates are specified for this parameter.

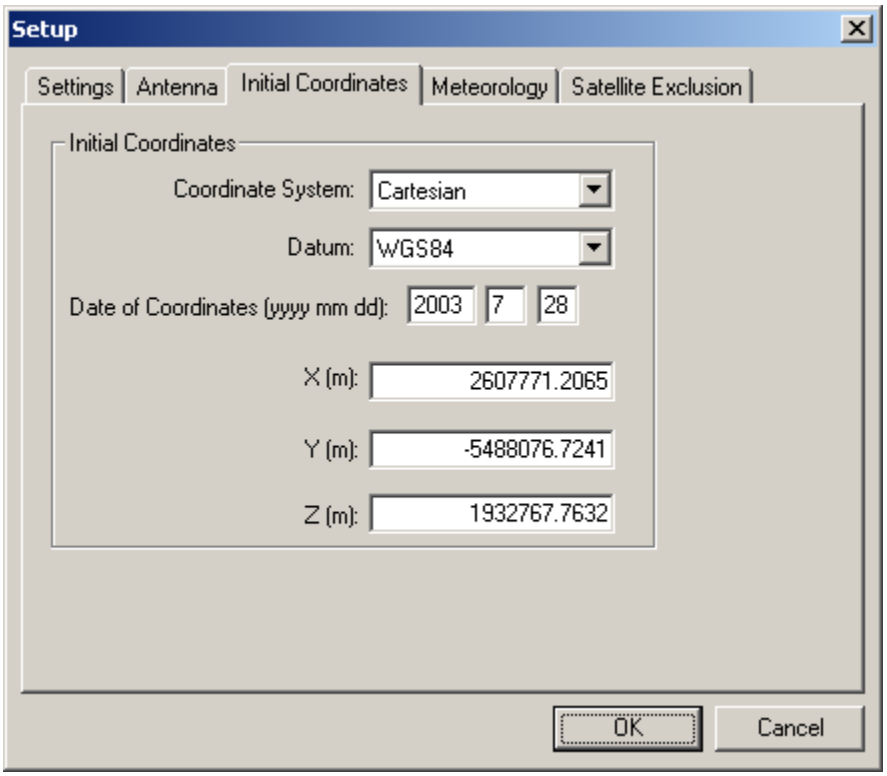


Figure 8.4: Cartesian *Initial Coordinates* tab in **Setup** window.

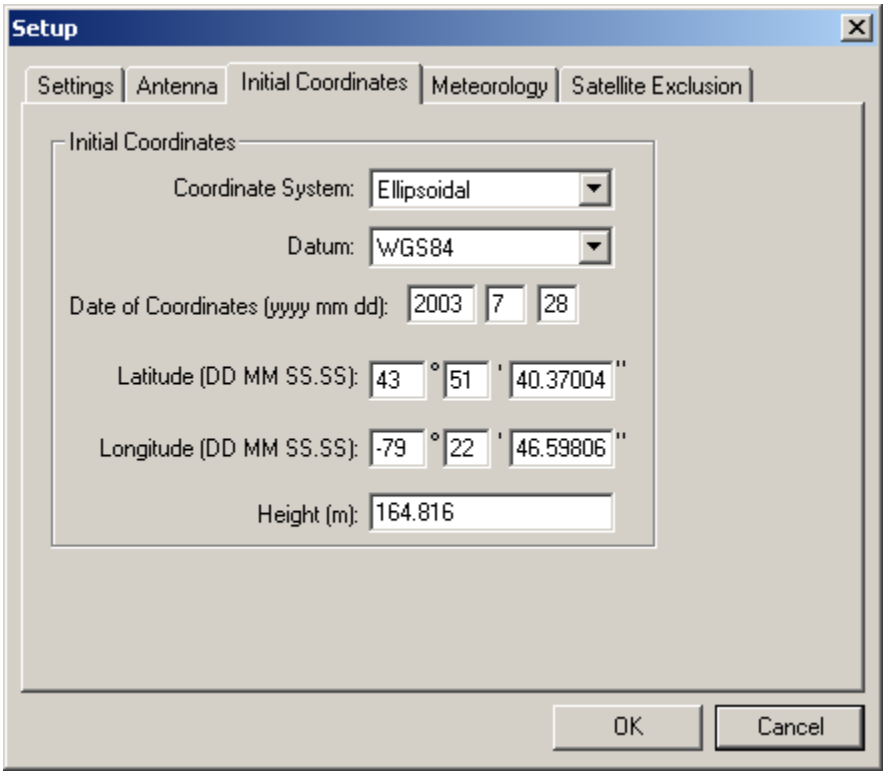


Figure 8.5: Ellipsoidal *Initial Coordinates* tab in **Setup** window.

DATUM

Select the datum with respect to which the approximate coordinates of the receiver are known from the DATUM drop down box. Three choices are supported: WGS84, ITRF00, and NAD83. The coordinate values that are entered must be in the datum that is specified in the DATUM parameter.

Note that currently WGS84 and ITRF00 are assumed to be consistent at the centimetre level. No official transformation parameters exist between these two reference frames. In the software, WGS84 and ITRF00 coordinates are treated exactly the same.

The transformation between NAD83 and WGS84, or equivalently, the transformation between NAD83 and ITRF00, and vice versa, is done using the following transformation parameters:

$$
\begin{array}{llll}
T_X(t_0) = 0.9956 & \dot{T}_X = 0.0007 & \varepsilon_X(t_0) = 25.915 & \dot{\varepsilon}_X = 0.067 \\
T_Y(t_0) = -1.9013 & \dot{T}_Y = -0.0007 & \varepsilon_Y(t_0) = 9.426 & \dot{\varepsilon}_Y = -0.757 \\
T_Z(t_0) = -0.5215 & \dot{T}_Z = 0.0005 & \varepsilon_Z(t_0) = 11.599 & \dot{\varepsilon}_Z = -0.051
\end{array}
$$

$$
S(t_0) = 0.62 \times 10^{-9} \quad \dot{S} = -0.18 \times 10^{-9}
$$

where T are the translations (in metres) and ε are the rotations (in milli arc seconds) at reference epoch 1997. The time derivatives of the translations and rotations are given by $\dot{T}$ and $\dot{\varepsilon}$, respectively. The scale factor is denoted by S, and its time derivative by $\dot{S}$. All time derivatives are per year.

Note that all processing in PPP is done in WGS84/ITRF00 except when NRCan GPS*C corrections are used for orbits and clocks. When this is the case, processing is done in NAD83.

DATE OF COORDINATES

Since the transformation between WGS84 (or equivalently, ITRF00) and NAD83 (or vice versa) includes time derivatives of the translations and rotations, the date of the coordinates must also be included.

For example, when transforming from ITRF00 to NAD83, the ITRF00 coordinates must first be projected from the date specified in the DATE OF COORDINATES parameter to the reference epoch of the transformation (1997), and then converted to NAD83. This is because the transformation by itself only transforms ITRF00 coordinates at the reference epoch to NAD83 (or vice versa).

As mentioned above, all processing is done in WGS84/ITRF00 except when NRCan GPS*C corrections are used for orbits and clocks. In the latter case, processing is done in NAD83. Since the coordinate date is only used when transforming between WGS84 (ITRF00) to NAD83 or vice versa, there are situations when the coordinate date specified under the DATE OF COORDINATES parameter is not used. For example, when IGS orbit and clock products are used, and the initial coordinates are in ITRF00, no transformation to NAD83 is made during processing. Similarly, when NRCan GPS*C corrections are used for orbits and clocks and the initial coordinates are in NAD83, no transformation to ITRF00 is made during processing. A

transformation may be done after processing is complete depending on the choice of datum specified for the output report file (described in Section 13).

XYZ

If the Cartesian coordinate system has been chosen, approximate X, Y and Z coordinates will need to be entered in the three appropriate boxes, in metres.

LATITUDE, LONGITUDE AND HEIGHT

If the Ellipsoidal coordinate system is chosen, the latitude, longitude and height values will need to be specified. Enter the latitude and longitude in degree-minute-second (DMS) format. Positive latitude refers to north, and positive longitude refers to east. Negative signs must be introduced in front of the degree value for either latitude or longitude if the approximate position of the receiver is either south or west, respectively.

After specifying the latitude and longitude, enter the approximate height of the receiver in metres for the HEIGHT parameter.

OK

Once all of the parameters have been specified and other parameters in the **Setup** window do not need to be changed, click on *OK* to exit and retain your parameter input. If the parameters in any of the other tabs need to be modified, simply click on the tabs and modify the parameters.

CANCEL

If you would like to close the window without saving the parameters that were specified, simply click on the *CANCEL* button or on the X in the top right corner of the window and your changes will not be retained. Note that the *CANCEL* button applies to all tabs in the **Setup** window. As such, changes to any parameters in any of the other tabs will not be retained when the *CANCEL* button is pressed.

8.4. Meteorology

The M*eteorology* tab is shown in Figure 8.6. This part of the **Setup** window requires the user to enter the approximate TEMPERATURE, PRESSURE, and HUMIDITY values at the receiver. Enter the TEMPERATURE in degrees Celsius, the PRESSURE in millibars, and the HUMIDITY in percent. The HUMIDITY parameter refers to relative humidity.

Note that when troposphere estimation is selected in PPP processing, the tropospheric error is treated as an unknown in the least-squares estimation process. The TEMPERATURE, PRESSURE, and HUMIDITY values are only used in the first epoch in order to obtain an approximate value for the tropospheric error. Generally, estimation of the tropospheric error yields better results. Troposphere modeling and estimation is further described in Section 10.3.

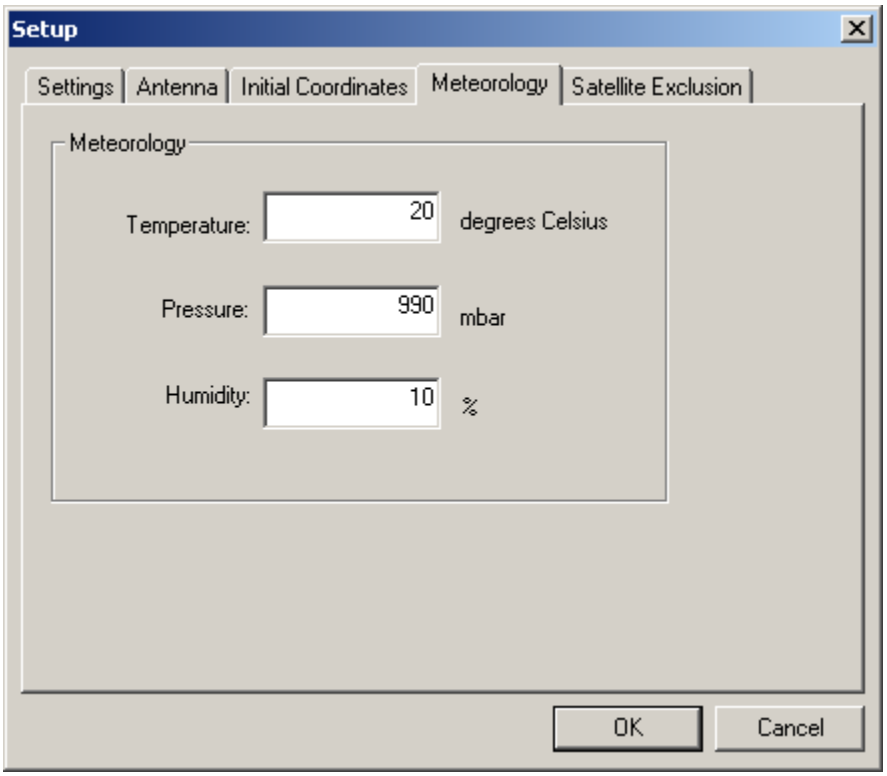


Figure 8.6: *Meteorology* tab in **Setup** window.

OK

Once all of the parameters have been specified and other parameters in the **Setup** window do not need to be changed, click on *OK* to exit and retain your parameter input. If the parameters in any of the other tabs need to be modified, simply click on the tabs and modify the parameters.

CANCEL

If you would like to close the window without saving the parameters that were specified, simply click on the *CANCEL* button or on the X in the top right corner of the window and your changes will not be retained. Note that the *CANCEL* button applies to all tabs in the **Setup** window. As such, changes to any parameters in any of the other tabs will not be retained when the *CANCEL* button is pressed.

8.5. Satellite Exclusion

This last part of the **Setup** window, shown in Figure 8.7, allows the user to eliminate certain satellites from processing. Simply select the checkbox(es) next to the PRN number(s) of the satellite(s) that you wish to exclude from processing. Use the *SELECT ALL* and *DESELECT ALL* buttons to select all satellites for exclusion or select none of the satellites for exclusion, respectively. Obviously, the *SELECT ALL* button is intended only to speed up the selection process when the user wants to exclude a large number of satellites. A warning message appears when less than four satellites have been retained for processing.

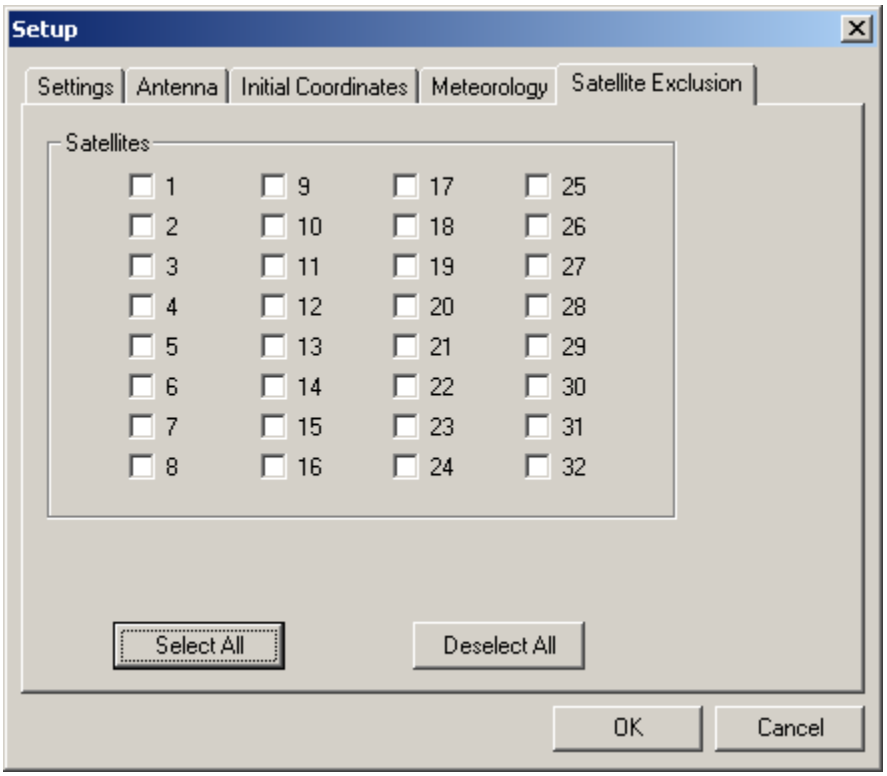


Figure 8.7: *Satellites Exclusion* tab in **Setup** window.

OK

Once all of the parameters have been specified and other parameters in the **Setup** window do not need to be changed, click on *OK* to exit and retain your parameter input. If the parameters in any of the other tabs need to be modified, simply click on the tabs and modify the parameters.

CANCEL

If you would like to close the window without saving the parameters that were specified, simply click on the *CANCEL* button or on the X in the top right corner of the window and your changes will not be retained. Note that the *CANCEL* button applies to all tabs in the **Setup** window. As such, changes to any parameters in any of the other tabs will not be retained when the *CANCEL* button is pressed.

9. Processing Modes

This section of the manual describes the various processing modes that are available in P³. There are four processing modes. They are listed below:

- SPP
- PPP
- Static Processing
- Kinematic Processing

9.1. SPP

SPP is a mode that only makes use of code measurements. Compared to PPP, which makes use of both code and carrier phase measurements, SPP provides positioning estimates of lower accuracy. In SPP mode, the user can perform processing with L1 C/A code only, or with L1 and L2 code. With the latter, an ionospheric-free code combination is used, effectively eliminating first-order ionospheric effects. If only L1 C/A code is used, no ionosphere elimination or reduction can be performed unless ionospheric parameters are contained in the broadcast navigation file.

SPP is supported in post-mission and real-time processing, and is available in static and kinematic modes. The parameters required for SPP are different whether post-mission or real-time processing has been selected. The remainder of this section describes the windows associated with each.

9.1.1. SPP Post-Mission Processing

The window associated with SPP post-mission processing is shown in Figure 9.1. It can be activated in post-mission mode using the *PROCESS* button or by selecting **SPP…** from the **PROCESS** menu.

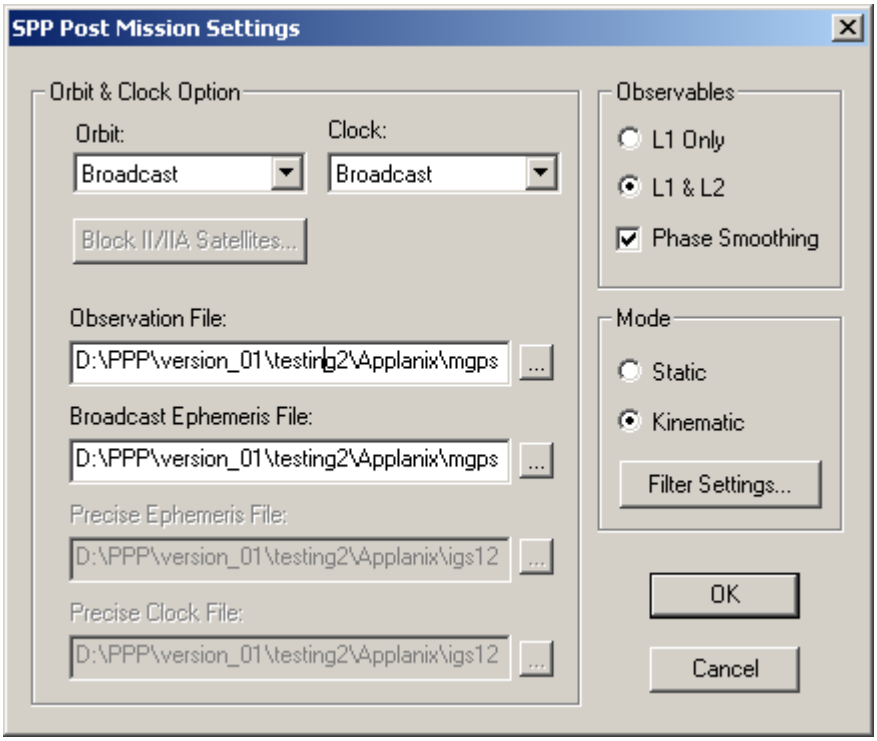


Figure 9.1: SPP post-mission settings.

ORBIT

Under the ORBIT parameter in the 'Orbit & Clock Option' panel, Broadcast, SP3, Broadcast+GPS•C, or Broadcast+JPL can be selected. Each of these options is described below. More information is provided under the 'Precise Ephemeris and Clock Files' heading below.

Broadcast – only broadcast ephemeris information contained in the navigation file will be used.

SP3 – orbit data will be obtained from an SP3 file that is available from the International GPS Service (IGS). Three types of SP3 files are available from the IGS: final, rapid, and ultra-rapid. Each SP3 file contains orbit and clock information at a 15 minute interval.

IGS provides precise satellite orbit and clock data with different precisions and latencies. As of November 23, 2003, they are: *ultra-rapid corrections* with accuracies of less than 5 cm and 0.2 ns, with a latency of 3 hours, *rapid corrections* with accuracies of less than 5 cm and 0.1 ns, with a latency of 17 hours, and *final corrections* with accuracies of less than 5 cm and less than 0.1 ns, with a latency of 13 days.

When an SP3 file is specified for orbits, broadcast ephemeris information contained in the navigation file is not used.

Broadcast+GPS·C – broadcast ephemerides contained in the navigation file will be corrected with NRCan's GPS·C real-time corrections.

Broadcast+JPL – broadcast ephemerides contained in the navigation file will be corrected with JPL's real-time corrections.

CLOCK

Similarly, under the CLOCK parameter, Broadcast, 5 Minutes, SP3, Broadcast+GPS·C, or Broadcast+JPL options are available. Each is described below. More information is provided under the 'Precise Ephemeris and Clock Files' heading below.

Broadcast – only broadcast clock information contained in the navigation file will be used.

SP3 – clock data will be obtained from an SP3 file that is available from the IGS. Refer to the SP3 option under the ORBIT heading above for a description of this file. Since the SP3 file contains both orbit and clock information, it only has to be specified once under the PRECISE EPHEMERIS FILE parameter when SP3 is selected for both the ORBIT and CLOCK parameters. In this case, the PRECISE CLOCK FILE parameter will become disabled.

When an SP3 file is specified for clocks, broadcast clock information contained in the navigation file is not used.

5 Minutes – this option allows the user to use the 5 minute clock files that are generated by the IGS. As the name suggests, data contained in these files is at an interval of 5 minutes. Using this file for the CLOCK parameter produces significantly better results compared with the use of the 15 minute clock data contained in the SP3 file due to the fact that less interpolation needs to be performed.

Broadcast+GPS·C – broadcast clock information contained in the navigation file will be corrected with NRCan's GPS·C real-time corrections.

Broadcast+JPL – broadcast clock information contained in the navigation file will be corrected with JPL's real-time corrections.

Note that using real-time corrections in post-mission mode requires that these corrections have been downloaded previously from the correction providers for the period of time corresponding to the observation data.

BLOCK II/IIA SATELLITES

The *BLOCK II/IIA SATELLITES* button, which appears disabled in Figure 9.1 above for post-mission SPP mode, is used to select Block II/IIA satellites for which a phase centre offset correction should be applied. This error only exists for Block II/IIA satellites. Furthermore, the phase centre offset correction only needs to be applied when precise satellite orbit or clock data is used. In Figure 9.1 above, since Broadcast was specified for the ORBIT and CLOCK parameters, the *BLOCK II/IIA SATELLITES* button is disabled. More

information about this correction, and the window that appears when the button is pressed is provided in Section 10.5.

OBSERVATION AND BROADCAST EPHEMERIS FILES

The OBSERVATION FILE parameter is the GPS observation file in RINEX format. This file must be specified. If it is not specified, not found by the software, or the format is incorrect, a warning message will be displayed. The BROADCAST EPHEMERIS FILE parameter must contain the broadcast navigation file in RINEX format. This file must be specified, although sometimes it may not be used (for example, when IGS precise orbit or clock data is used).

Note that all null epochs (epochs for which no satellites have been observed) must be removed manually from RINEX observation files before they are used in the software. This is because the program automatically stops processing when it encounters such epochs. For example, the epoch at $19^h03^m45^s$ in Figure 9.2 below is a null epoch. These epochs can be removed by searching and removing all lines in the observation file that contain a "0 0 0" string (there are two spaces between the zeros).

```
03 09 15 19 03 44.0000000  0  6G25G16G 6G20G 1G14
  20824053.50049 109431158.84449      -977.31249  20824050.33648  85271017.71148
      -761.68848
  20949022.13349 110087848.54349      2101.93849  20949017.86747  85782757.93447
      1637.68847
  23386220.63348 122895421.68048       228.81248  23386219.02347  95762685.87947
       178.12547
  22030623.53148 115771704.36348      -647.62548  22030620.85946  90211726.44946
      -504.81246
  23068202.08647 121224225.44947      3011.31247  23068201.10945  94460427.35245
      2346.31245
  23583405.38348 123931644.43848     -3248.81248  23583402.68845  96570087.62145
     -2531.68845
 03 09 15 19 03 45.0000000  0  0
 03 09 15 19 03 46.0000000  0  4G 2G 6G20G 1
  22434148.87548 117892246.66048      2593.18848  23386132.84449 122894960.13759
       228.87549
  23386132.84449 122894960.13749       228.87549

  22030867.10947 115772987.40647      -644.93847

  23067053.93047 121218185.62547      3013.75047
```

Figure 9.2: Example of null epochs in observation files.

PRECISE EPHEMERIS AND CLOCK FILES

The PRECISE EPHEMERIS FILE and PRECISE CLOCK FILE parameters refer to precise satellite orbit and clock files, respectively. They will be enabled for specific ORBIT and CLOCK selections. When SP3 is specified for both parameters, only the PRECISE EPHEMERIS FILE parameter needs to be specified. This is because the SP3 file contains precise satellite orbit and clock data, which will both be read by the software from the single SP3 file specified under the PRECISE EPHEMERIS FILE parameter. In this situation, the PRECISE CLOCK FILE parameter will be automatically disabled.

When using either GPS•C or JPL corrections, make sure to use them for both orbits and clocks. In other words, both the ORBIT and CLOCK parameters should either be set to Broadcast+GPS•C or Broadcast+JPL.

OBSERVABLES

In the OBSERVABLES panel, two observables are available for post-mission SPP: L1 ONLY or L1 & L2. The availability of these choices will depend on what is in the GPS observation file specified in the OBSERVATION FILE parameter. If only L1 code observations exist, then the L1 & L2 option will be disabled. If the file is incorrectly specified, not found by the software, or in an improper format, both options will be disabled.

When the L1 ONLY option is specified, ionospheric-free combinations cannot be formed. As such, the software will check to see if ionospheric parameters exist in the navigation file specified under BROADCAST EPHEMERIS FILE parameter. If they do not, a warning message will be displayed notifying the user of this, and asking if the user wants to continue with processing anyway.

When the L1 & L2 option is selected when both code observations exist in the RINEX observation file, an ionospheric-free code combination will be formed between L1 and L2 code observations.

PHASE SMOOTHING

The PHASE SMOOTHING option is discussed in Section 10.2.

STATIC/KINEMATIC

The STATIC and KINEMATIC options are described in Sections 9.3 and 9.4, respectively.

FILTER SETTINGS

The *FILTER SETTINGS* button is discussed in Section 10.6.

OK

Once all of the settings have been specified, click on *OK* to save them.

CANCEL

Click on *CANCEL* and changes that were made to the parameters will not be retained.

9.1.2. SPP Real-Time Processing

The window associated with SPP real-time processing is shown in Figure 9.3. It can be activated in real-time mode using the *PROCESS* button or by selecting **SPP…** from the **PROCESS** menu.

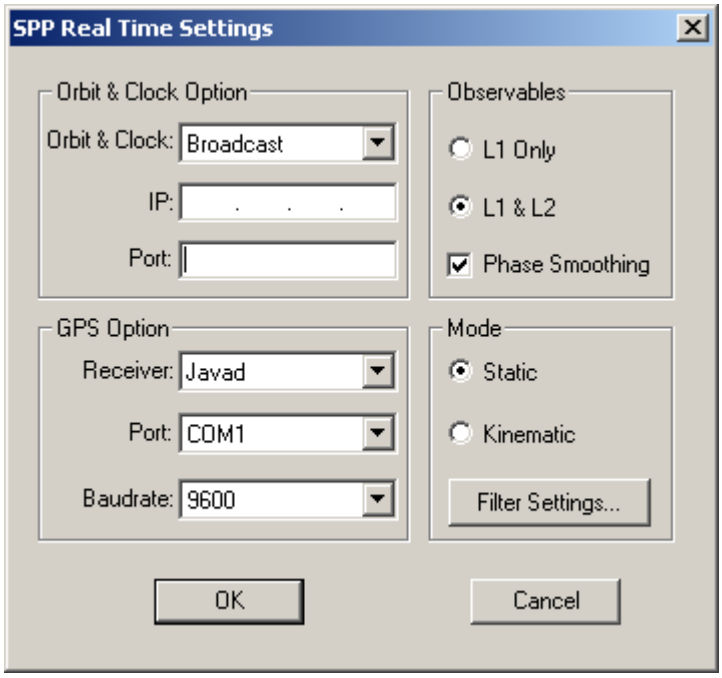


Figure 9.3: SPP real-time settings.

ORBIT AND CLOCK OPTION PANEL

In the ORBIT & CLOCK parameter, select Broadcast, Broadcast+GPS·C or Broadcast+JPL. When either Broadcast+GPS·C or Broadcast+JPL is selected, options for the IP address and PORT will have to be specified as shown in Figure 9.3. The three orbit and clock possibilities are described below.

Broadcast – only broadcast orbit and clock information contained in the navigation file will be used.

Broadcast+GPS·C – broadcast orbit and clock information contained in the navigation file will be corrected with NRCan's GPS·C real-time corrections.

Broadcast+JPL – broadcast orbit and clock information contained in the navigation file will be corrected with JPL's real-time corrections.

The IP and PORT parameters should be obtained from either the GPS·C or JPL correction providers.

GPS OPTION PANEL

Select the receiver type under the RECEIVER parameter, the PORT to which the receiver is connected, and the BAUDRATE. Note that at this time only the Javad receiver can be used for real-time applications. In the future, other receivers will be incorporated into the software.

OBSERVABLES

In the Observables panel, select either L1 ONLY or L1 & L2, depending on the observations that will be obtained from the Javad receiver. Refer to the Observables heading in Section 9.1.1 for more information about these observables.

PHASE SMOOTHING

The PHASE SMOOTHING option is discussed in Section 10.2.

STATIC/KINEMATIC

The STATIC and KINEMATIC options are described in Sections 9.3 and 9.4, respectively.

FILTER SETTINGS

The *FILTER SETTINGS* button is discussed in Section 10.6.

OK

Once all of the settings have been specified, click on *OK* to save them.

CANCEL

Click on *CANCEL* and changes that were made to the parameters will not be preserved.

9.2. PPP

PPP is a mode that makes use of both code and carrier phase measurements, providing greater positioning accuracy compared to SPP. As with SPP, both static and kinematic processing can be performed, and phase smoothing of code can be applied. PPP mode also allows the user to perform tropospheric and velocity estimation as well as backward processing.

Two algorithms can be applied: Traditional Model or UoC Model. The latter was developed in the Department of Geomatics Engineering at the University of Calgary. The UoC Model has shown better positioning accuracy than the Traditional Model. Both models are described in more detail in Section 10.1.

The parameters required for PPP are different whether post-mission or real-time processing has been selected. The remainder of this section describes the windows associated with each.

9.2.1. PPP Post-Mission Processing

The window associated with post-mission PPP processing is shown in Figure 9.4. It can be activated in post-mission mode using the *PROCESS* button or by selecting **PPP…** from the **PROCESS** menu.

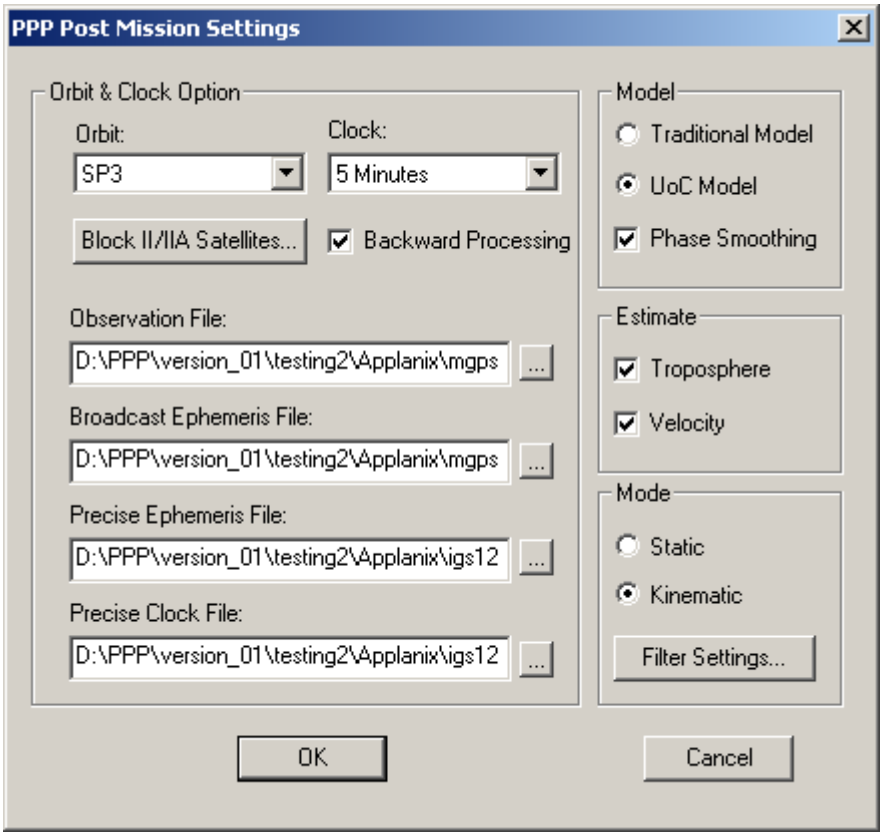


Figure 9.4: PPP post-mission settings.

ORBIT

Under the ORBIT parameter in the 'Orbit & Clock Option' panel, SP3, Broadcast+GPS•C, or Broadcast+JPL can be selected. Each of these options is described below. More information is provided under the 'Precise Ephemeris and Clock Files' heading below.

SP3 – orbit data will be obtained from an SP3 file that is available from the International GPS Service (IGS). Three types of SP3 files are available from the IGS: final, rapid, and ultra-rapid. Each SP3 file contains orbit and clock information at a 15 minute interval.

IGS provides precise satellite orbit and clock data with different precisions and latencies. As of November 23, 2003, they are: *ultra-rapid corrections* with accuracies of less than 5 cm and 0.2 ns, with a latency of 3 hours, *rapid corrections* with accuracies of less than 5 cm and 0.1 ns, with a latency of 17 hours, and *final corrections* with accuracies of less than 5 cm and less than 0.1 ns, with a latency of 13 days.

When an SP3 file is specified for orbits, broadcast ephemeris information contained in the navigation file is not used.

Broadcast+GPS·C – broadcast ephemerides contained in the navigation file will be corrected with NRCan's GPS·C real-time corrections.

Broadcast+JPL – broadcast ephemerides contained in the navigation file will be corrected with JPL's real-time corrections.

CLOCK

Similarly, under the CLOCK parameter, 5 Minutes, SP3, Broadcast+GPS·C, or Broadcast+JPL options are available. Each is described below. More information is provided under the 'Precise Ephemeris and Clock Files' heading below.

SP3 – clock data will be obtained from an SP3 file that is available from the IGS. Refer to the SP3 option under the ORBIT heading above for a description of this file. Since the SP3 file contains both orbit and clock information, it only has to be specified once under the PRECISE EPHEMERIS FILE parameter when SP3 is also selected for both the ORBIT and CLOCK parameters. In this case, the PRECISE CLOCK FILE parameter will become disabled.

When an SP3 file is specified for clocks, broadcast clock information contained in the navigation file is not used.

5 Minutes – this option allows the user to use the 5 minute clock files that are generated by the IGS. As the name suggests, data contained in these files is at an interval of 5 minutes. Using this file for the CLOCK parameter produces significantly better results compared with the use of the SP3 file due to the fact that less interpolation needs to be performed.

Broadcast+GPS·C – broadcast clock information contained in the navigation file will be corrected with NRCan's GPS·C real-time corrections.

Broadcast+JPL – broadcast clock information contained in the navigation file will be corrected with JPL's real-time corrections.

Note that using real-time corrections in post-mission mode requires that these corrections have been downloaded previously from the correction providers for the period of time corresponding to the observation data.

BLOCK II/IIA SATELLITES

The *BLOCK II/IIA SATELLITES* button, which appears enabled in Figure 9.3 above for post-mission PPP mode, is used to select Block II/IIA satellites for which a phase centre offset correction can be applied. This error only exists for Block II/IIA satellites. Furthermore, the phase centre offset correction only needs to be applied when precise satellite orbit or clock data is used. More information about this correction, and the window that appears when the button is pressed, is provided in Section 10.5.

BACKWARD PROCESSING

Backward processing is available in post-mission PPP mode. This option is further described in Section 10.7.

OBSERVATION AND BROADCAST EPHEMERIS FILES

The OBSERVATION FILE parameter is the GPS observation file in RINEX format. This file must be specified. If it is not specified, not found by the software, or the format is incorrect, a warning message will be displayed. The BROADCAST EPHEMERIS FILE parameter must contain the broadcast navigation file in RINEX format. This file must be specified, although sometimes it may not be used (for example, when IGS precise orbit or clock data is used).

Note that all null epochs (epochs for which no satellites have been observed) must be removed manually from RINEX observation files before they are used in the software. Refer to the 'Observation and Broadcast Ephemeris Files' heading in Section 9.1.1 for further details.

PRECISE EPHEMERIS AND CLOCK FILES

The PRECISE EPHEMERIS FILE and PRECISE CLOCK FILE parameters refer to precise satellite orbit and clock files, respectively. They will be enabled for specific ORBIT and CLOCK selections. When SP3 is specified for both parameters, only the PRECISE EPHEMERIS FILE parameter needs to be specified. This is because the SP3 file contains precise satellite orbit and clock data, which will both be read by the software from the single SP3 file specified under PRECISE EPHEMERIS FILE. In this situation, the PRECISE CLOCK FILE parameter will be automatically disabled.

When using either GPS•C or JPL corrections, make sure to use them for both orbits and clocks. In other words, both the ORBIT and CLOCK parameters should either be set to Broadcast+GPS•C or Broadcast+JPL.

MODEL

In PPP mode, the user can select between the Traditional Model and the UoC Model. These two models are described in Section 10.1.

TROPOSPHERE

The user may choose to model the troposphere or to estimate it as an unknown in the least-squares process. This is described in Section 10.3.

VELOCITY ESTIMATION

The user may choose to estimate the velocity of the receiver when Doppler observations are available in the RINEX observation file. Velocity estimation is described in Section 10.4.

PHASE SMOOTHING

The PHASE SMOOTHING option is discussed in Section 10.2.

STATIC/KINEMATIC

The STATIC and KINEMATIC options are described in Sections 9.3 and 9.4, respectively.

FILTER SETTINGS

The *FILTER SETTINGS* button is discussed in Section 10.6.

OK

Once all of the settings have been specified, click on *OK* to save them.

CANCEL

Click on *CANCEL* and changes that were made to the parameters will not be preserved.

9.2.2. PPP Real-Time Processing

The window associated with PPP real-time processing is shown in Figure 9.5. It can be activated in real-time mode using the *PROCESS* button or by selecting **PPP…** from the **PROCESS** menu.

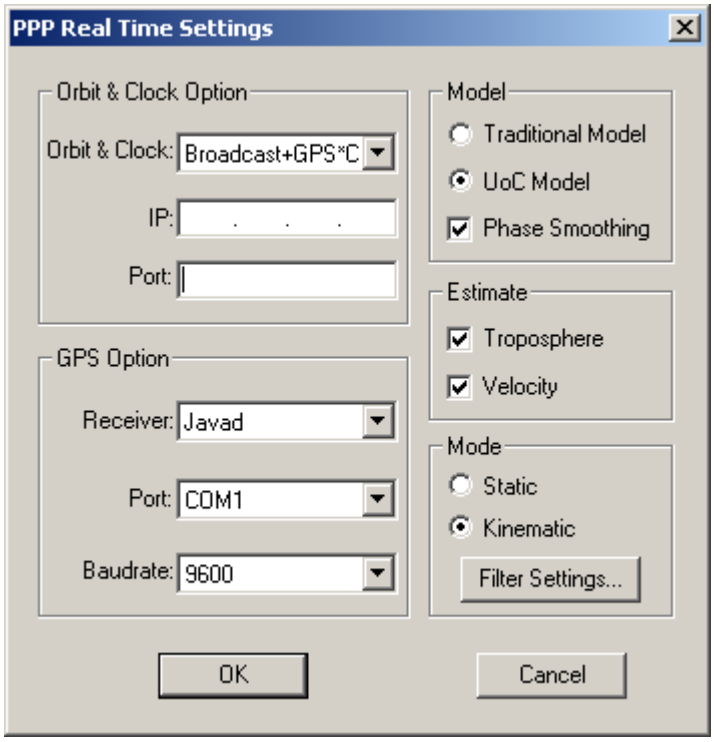


Figure 9.5: PPP real-time settings.

ORBIT AND CLOCK OPTION PANEL

In the ORBIT & CLOCK parameter, select Broadcast+GPS·C or Broadcast+JPL. When either Broadcast+GPS·C or Broadcast+JPL is selected, options for the IP address and PORT will have to be specified as shown in Figure 9.5. The two orbit and clock possibilities are described below.

Broadcast+GPS·C – broadcast orbit and clock information contained in the navigation file will be corrected with NRCan's GPS·C real-time corrections.

Broadcast+JPL – broadcast orbit and clock information contained in the navigation file will be corrected with JPL's real-time corrections.

The IP and PORT parameters should be obtained from either the GPS·C or JPL correction providers.

GPS OPTION PANEL

Select the receiver type under the RECEIVER parameter, the PORT to which the receiver is connected, and the BAUDRATE. Note that at this time only the Javad receiver can be used for real-time applications. In the future, other receivers will be incorporated into the software.

MODEL

As was the case for post-mission PPP mode, the user can select between the Traditional Model and the UoC Model. These two models are described in Section 10.1.

TROPOSPHERE

The user may choose to model the troposphere or to estimate it as an unknown in the least-squares process. This is described in Section 10.3.

VELOCITY ESTIMATION

The user may choose to estimate the velocity of the receiver when Doppler observations are available in the RINEX observation file. Velocity estimation is described in Section 10.4.

PHASE SMOOTHING

The PHASE SMOOTHING option is discussed in Section 10.2.

STATIC/KINEMATIC

The STATIC and KINEMATIC options are described in Sections 9.3 and 9.4, respectively.

FILTER SETTINGS

The *FILTER SETTINGS* button is discussed in Section 10.6.

OK

Once all of the settings have been specified, click on *OK* to save them.

CANCEL

Click on *CANCEL* and changes that were made to the parameters will not be preserved.

9.3. Static Processing

Static processing is performed on data from a receiver that has remained stationary with respect to the Earth's surface. Static processing may be done in either post-mission or real-time mode. In static processing, the receiver's position is computed at each epoch. These solutions appear as red dots in the Static/Kinematic Solution Window when the Picture View is open.

9.4. Kinematic Processing

Kinematic processing is performed on data from a receiver that has moved with respect to the Earth's surface. Kinematic processing may be done in either post-mission or real-time mode. The receiver's position is computed at each epoch, and displayed as a trajectory in the Static/Kinematic Solution Window in the Picture View.

10. Processing Options

This section describes the processing options that are available in some of the processing modes described in the previous section. The various options, and the modes in which they are available, are listed in Table 10.1.

Table 10.1: Processing options and their modes.

Processing Option	Available Mode(s)
Traditional / UoC Model	PPP only.
Phase Smoothing of Code	All modes.
Troposphere	PPP only.
Velocity Estimation	Real-time PPP mode when Velocity estimation is selected or post-mission PPP mode when Doppler observations are present in the observation file and Velocity estimation is selected. Only available in kinematic mode.
Block II/IIA Satellite Phase Centre Offset Correction	Post-mission only when IGS precise orbit or clock data is used.
Filter Settings	All modes.
Backward Processing	PPP only.

10.1. Traditional / UoC Model

The user can choose between the Traditional Model and the UoC Model when processing in PPP mode.

In the Traditional Model, traditional ionospheric-free code and carrier phase combinations are formed. These combinations are presented in Appendix B. The UoC Model forms three ionospheric-free combinations: between L1 code and L1 phase, between L2 code and L2 phase, and between L1 phase and L2 phase. The last of these is the same as the traditional ionospheric-free phase combination. These combinations are also provided in Appendix B. The advantages and disadvantages of the two models are discussed in Section 4.4.

10.2. Phase Smoothing of Code

Phase smoothing of code reduces the code noise level by applying a recursive smoothing procedure that makes use of the ionosphere-free phase measurement. The smoothing process effectively reduces code noise and also a significant portion of multipath. Further details about the phase smoothing procedure are provided in Appendix D. Phase smoothing should always be applied for best results, especially when code observations are used in processing.

10.3. Troposphere

When the user selects the TROPOSPHERE parameter in PPP mode, the troposphere will be estimated as an unknown in the least-squares process, as described in Section 10.3.1. Otherwise, it will be modeled, as described in Section 10.3.2.

10.3.1. Estimation

When the user selects TROPOSPHERE in the **PPP** window in either post-mission or real-time mode, the zenith tropospheric error will be estimated in the least-squares process as an unknown along with the unknown three coordinates of the receiver and the receiver clock offset. In this situation, the TEMPERATURE, PRESSURE, and HUMIDITY values entered in the **Setup** window under the *Meteorology* tab (see Section 8.4) will only be used in the first epoch in order to obtain an approximate value for the tropospheric error.

During the least-squares process, the zenith tropospheric error will be estimated at each epoch, and the Neill mapping function will be applied. This function will propagate the zenith tropospheric delay into the various elevation angles formed by the receiver-satellite pairs.

10.3.2. Modeling

If processing in SPP mode, or if troposphere estimation is not selected in PPP mode, then the zenith tropospheric delay will be modeled based on the TEMPERATURE, PRESSURE, and HUMIDITY values entered by the user.

The modeled troposphere correction is nearly a constant value. This is because it is a function of the specified TEMPERATURE, PRESSURE and HUMIDITY values specified by the user in the **Setup** window under the *Meteorology* tab (see Section 8.4). The modelled troposphere correction also depends on the computed latitude of the receiver at each epoch. In static mode, and especially when the user specifies good initial coordinates, the computed latitude should remain fairly constant. As such, the zenith tropospheric error will be virtually identical from epoch to epoch. In kinematic mode, the computed latitude of the receiver may change more significantly at each epoch, and small variations in the zenith tropospheric error will be introduced from epoch to epoch.

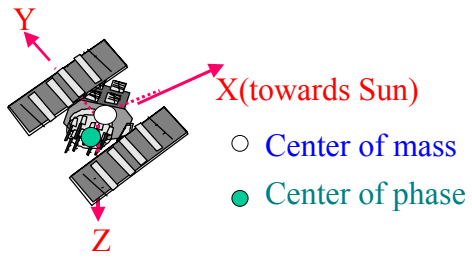
10.4. Velocity Estimation

When the user selects the VELOCITY parameter in PPP mode, the velocity of the receiver will be estimated in all three coordinate directions in the least-squares process. Of course, velocity estimation can only be performed when Doppler observations exist in the RINEX observation file. If they do not, the velocity option will be disabled. The velocity option is only available in kinematic mode.

10.5. Block II/IIA Satellite Phase Centre Offset Correction

Satellite antenna offsets should be applied when IGS precise products are used. The reason for this satellite-based correction originates from the separation between the GPS satellite centre of mass and the phase centre of its antenna. Because the force models used by the IGS community for satellite orbit modeling refer to the satellite centre of mass, their GPS precise satellite coordinates and clock products also refer to this point. However, the broadcast ephemerides in the GPS navigation message and GPS measurements refer to the satellite antenna phase centre. As a result, users who apply the IGS products must know satellite phase centre offsets and the orientation of the offset vector in space as the satellite orbits the Earth.

The phase centres for most satellites are offset both in the body Z coordinate direction (towards the Earth) and in the body X coordinate direction (on the plane containing the Sun) [Kouba and Héroux, 2000]. Refer to the figure below for these offsets.



Antenna phase centre offsets in satellite fixed reference frame (metres)

	X	Y	Z
Block II/IIA:	0.279	0.000	1.023
Block IIR :	0.000	0.000	0.000

Figure 10.1: IGS Conventional Antenna Phase Centres in Satellite Fixed Reference Frame

Not all satellites have antenna phase centre offsets. Block IIR and later satellites do not have to apply this correction because the satellite centre of mass point and the phase centre point of its antenna are equivalent.

The antenna phase centre offset correction can be applied to Block II/IIA satellites using the *BLOCK II/IIA SATELLITES* button in post-mission SPP and PPP mode. Clicking on this button activates the window shown in Figure 10.2.

A note appears at the bottom of the window direction users to a current listing of Block II/IIA satellites. As the satellite constellation changes, Block II/IIA satellites will be replaced by ones that do not require this correction.

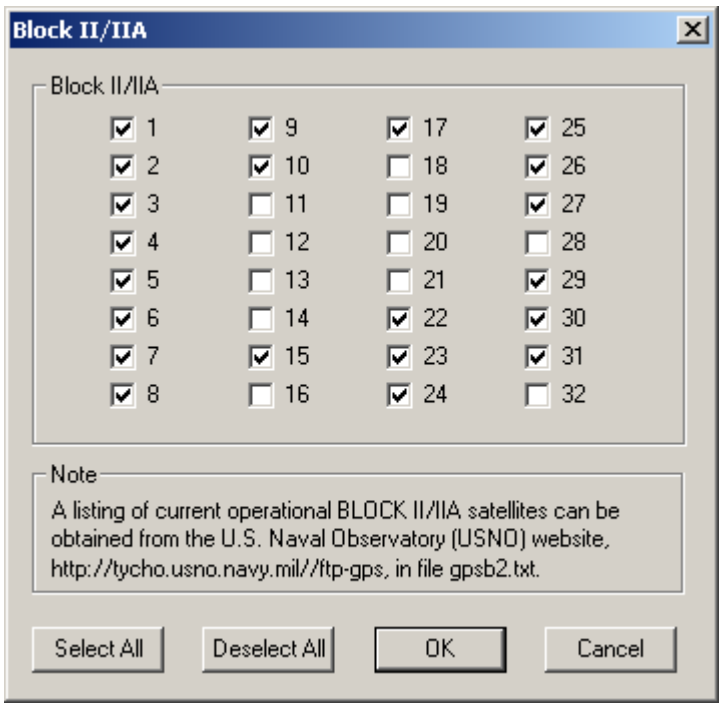


Figure 10.2: Satellite selection for BLOCK II/IIA offset correction

10.6. Filter Settings

The window associated with filter settings is shown in Figure 10.3. This dialog can be opened when either static or kinematic processing is done. Refer to Table 10.3 for sample values for static processing, and Table 10.4 for kinematic processing.

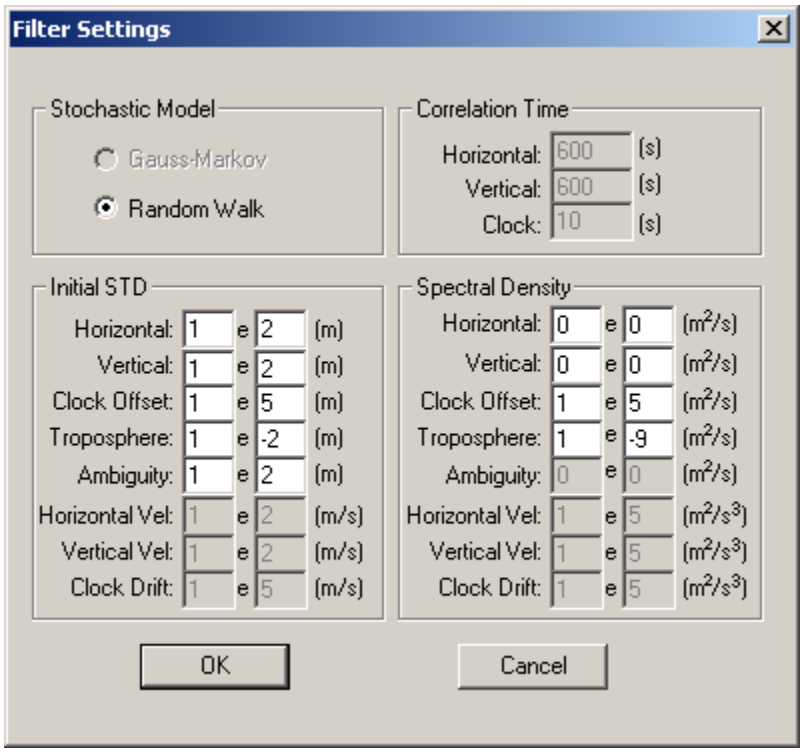


Figure 10.3: Filter Settings.

Changing the parameters in this window requires familiarity with the Kalman filter and the details associated with the creation of the error covariance matrix (P_k) as well as the spectral density matrix (Q_k).

Currently, only the Random Walk stochastic model is supported in P^3. The Gauss-Markov option will be disabled.

In the Initial STD panel, parameters associated with the error covariance matrix (P_k) can be specified. In SPP mode, only the standard deviations associated with horizontal position, vertical position, and clock offset are enabled. In PPP mode, the ambiguity standard deviation can also be specified. Furthermore, if troposphere estimation has been selected in the **PPP** window, the troposphere standard deviation parameter is enabled.

The modes described above, which allow users to specify standard deviation parameters in the Initial STD panel, also apply to the parameters in the Spectral Density panel. The modes in which the various parameters are available are listed in Table 10.2.

Table 10.2: Availability of Initial STD and Spectral Density parameters.

Parameter	Available Mode(s)
Horizontal	All modes.
Vertical	All modes.
Clock Offset	All modes.
Troposphere	Post-mission or real-time PPP mode when TROPOSPHERE estimation is selected.
Ambiguity	Post-mission or real-time PPP mode.
Horizontal Vel	Post-mission or real-time PPP mode when VELOCITY estimation is selected (kinematic mode only).
Vertical Vel	Post-mission or real-time PPP mode when VELOCITY estimation is selected (kinematic mode only).
Clock Drift	Post-mission or real-time PPP mode when VELOCITY estimation is selected (kinematic mode only).

For users not familiar with either the Initial STD or Spectral Density parameters, the values given in Table 10.3 and 10.4 can be used for static and kinematic processing, respectively. Only the horizontal and vertical spectral density values have different values for static vs. kinematic processing.

Table 10.3: Sample Initial STD and Spectral Density values for static processing.

Parameter	Initial STD	Spectral Density
Horizontal	1e0 *	0e0
Vertical	1e0 *	0e0
Clock Offset	1e5	1e5
Troposphere	1e-2	1e-9
Ambiguity	1e2	
Horizontal Vel	1e2	1e2
Vertical Vel	1e2	1e2
Clock Drift	1e5	1e5

Table 10.4: Sample Initial STD and Spectral Density values for kinematic processing.

Parameter	Initial STD	Spectral Density
Horizontal	1e0 *	1e2
Vertical	1e0 *	1e2
Clock Offset	1e5	1e5
Troposphere	1e-2	1e-9
Ambiguity	1e2	
Horizontal Vel	1e2	1e2
Vertical Vel	1e2	1e2
Clock Drift	1e5	1e5

* Initial STD values of 1e0 for the horizontal and vertical assume very good approximate coordinates for the receiver (at about the decimetre level). When these initial coordinates are not known with high accuracy, values of 1e2 can be input for the horizontal and vertical Initial STD parameters.

10.7. Backward Processing

When the BACKWARD PROCESSING parameter is selected in post-mission PPP mode, processing will continue backwards after all forward processing has been completed. This option can be used to obtain better positioning results after the combined ambiguity term in the Traditional Model or the L1 and L2 ambiguity terms in the UoC Model have converged.

11. Processing Commands

Three processing commands can be used to initiate, pause and stop processing. These are the *RUN, PAUSE* and *STOP* buttons. These are described in the following three sections.

11.1. RUN Button

Use this button to begin processing with the specified parameters. Note that when processing is taking place, parameters may not be modified. Use the *STOP* button to terminate processing, modify the required parameters, and use the *RUN* button to start processing with the new parameter configuration.

11.2. PAUSE Button

Use this button to pause processing at any time. This is especially useful when wanting to inspect some of the processing values, residuals, or other information provided in the Picture View for specific epochs. Press the *PAUSE* button again to resume processing.

As is the case with the *RUN* button, parameters may not be modified when processing is paused. To modify parameters, use the *STOP* button to terminate processing, modify the required parameters, and use the *RUN* button to start processing with the new parameter configuration.

11.3. STOP Button

Use this button to stop processing before completion. Note that once processing is stopped, it can only be started from the beginning at a later time. The output LOG file and the optional REPORT file, described in Section 12 and 13, respectively, will contain output information up to when the *STOP* button was pressed. All options in the Menu and Button bars are available when processing is stopped.

12. Logging File

The logging file is output automatically by P[3]. The path and name of the file can be set in the *Settings* tab of the **Setup** dialog (see Section 8.1.4). Header information in this file lists parameters associated with the program run. The remainder of the file contains information for each processed epoch.

The LOG file is the only source of information for the generation of the report file (Section 13) and various graphs (Section 14). As such, graphs can be displayed and/or the report file can be generated at a later time after the program has been closed.

HEADER

The header of the LOG file is shown in Figure 12.1. Generally, the header of the P[3] LOG file summarizes the processing options and parameters that were specified for the last program run. In Figure 12.1, the header information was extracted from the P[3] LOG file that was obtained when processing the data contained in the Quick Start Guide (Section 5).

```
                Station Mode : Static
     Initial PLH (DDMMSS.SS) : 174524.83256  -643503.55192  -31.94024
            Initial XYZ (m) : 2607771.20650  -5488076.72410  1932767.76320
   Initial Coordinate System : WGS84
    Coord. Date (yyyy mm dd) : 2003 7 28
                 System Mode : Post Mission
           Processing Mode : PPP
           Satellite Orbit : SP3
           Satellite Clock : 5 Minutes
    Result Coordinate System : ITRF00
          Observation File : D:\PPP\manual\DataSet2\CRO12090.03O
   Broadcast Ephemeris File : D:\PPP\manual\DataSet2\cro12090.03n
     Precise Ephemeris File : D:\PPP\manual\DataSet2\igr12291.sp3
         Precise Clock File : D:\PPP\manual\DataSet2\igr12291.clk
           Antenna PCV File : D:\PPP\igs_01_mod.pcv
                Troposphere : Estimate
          Estimate Velocity : No
         Estimate Ambiguity : Yes
            Ambiguity Model : UofC
               Phase Smooth : Yes
       Antenna Vendor/Type : TURBOROGUE     AOAD/M_T
     Marker to ARP E/N/H (m) : 0.0000    0.0000    0.0814
        ARP to APC E/N/H (m) : 0.0000    0.0000    0.0822
     Antenna PCV Corrections : No
          GPS UTC Offset (s) : 13
    Observation Interval (s) : 0.0
     BLOCK II/IIA Satellites : 1  2  3  4  5  6  7  8  9  10 15 17 22 23 24 25 26 27 29 30 31
         Excluded Satellites :
Temperature (degree Celsius) : 20.0
            Pressure (mbar) : 990.0
               Humidity (%) : 50.0
  Elevation Cut-Off (degree) : 10.0
               GDOP Cut-Off : 20.0
       Apriori Code STD (m) : 0.151
      Apriori Phase STD (m) : 0.006
Apriori Phase Rate STD (m/s) : 0.002
        Backward Processing : Yes
Initial STD/Spectral Density
                 Horizontal : 1e+002 m      0e+000 m^2/s
                   Vertical : 1e+002 m      0e+000 m^2/s
               Clock Offset : 1e+005 m      1e+005 m^2/s
                Troposphere : 1e-002 m      1e-009 m^2/s
                  Ambiguity : 1e+002 m      0e+000 m^2/s
                              END OF HEADER
```

Figure 12.1: P[3] LOG file header.

The majority of the header file simply lists the parameters that were specified by the user. In fact, only the APRIORI CODE STD and APRIORI PHASE STD parameters do not reflect the values specified by the user. These values are computed as follows:

$$\sigma_{0/CODE}=\frac{1}{2}\left(\sigma_{CODE}+\sigma_{PHASE}\right) \quad \text{(for UoC Model)} \quad (12.1)$$

$$\sigma_{0/CODE}=3\sigma_{CODE} \quad \text{(for Traditional Model)} \quad (12.2)$$

$$\sigma_{0/PHASE}=3\sigma_{PHASE} \quad \text{(for UoC and Traditional Models)} \quad (12.3)$$

Where:

σ_{CODE} – CODE STD parameter specified in the *Settings* tab of the **Setup** window (see Section 8.1.3) for a single observable.

σ_{PHASE} – PHASE STD parameter specified in the *Settings* tab of the **Setup** window (see Section 8.1.3) for a single observable.

$\sigma_{0/CODE}$ – Apriori Code STD as it appears in the LOG file for the ionospheric-free code combination.

$\sigma_{0/PHASE}$ – Apriori Phase STD as it appears in the LOG file for the ionospheric-free phase combination.

Some parameters do not appear in the header of the LOG file simply because they are not applicable for the processing mode and/or processing options that were specified before the program was run.

PROCESSING INFORMATION FOR INDIVIDUAL EPOCHS

Note that when NRCan GPS*C corrections are used for orbits and clocks, processing is done in the NAD83 datum in P^3. As such, coordinates output at each epoch in the LOG file are in NAD83. When other precise orbit and clock products are used, or broadcast data from the navigation message is used (in SPP mode), processing is done in the WGS84 (ITRF00) datum. In this case, coordinates output at each epoch will be in WGS84 (ITRF00) in the LOG file. The 'Result Coordinate System' parameter in the header of the LOG file (see Figure 12.1) shows which datum the output coordinates are in.

For each epoch at which a solution was computed, processing information is output to the LOG file. At times, a solution is not computed at a particular epoch because either not enough satellites were available for computations, the solution did not converge, etc. No data is output to the LOG file for such epochs.

Processing information for a sample epoch is shown in Figure 12.2. The information contained in Figure 12.2 corresponds to the first processed epoch of the P^3 LOG file that was obtained when processing the data contained in the Quick Start Guide (Section 5).

BEGIN OF EPOCH (GPS / UTC)	87330.0	2003 7 28 0 15 30.0					
PLH (DDMMSS.SS) Clk ZTD (m)	174524.82621	-643503.52985	-32.559	21.522	2.388		
XYZ (m)	2607771.566	-5488075.966	1932767.389				
Satellites tracked / used	7 7						
GDOP PDOP HDOP VDOP TDOP	3.2 2.7 1.2 2.4 1.7						
Sigma PLH Clk ZTD (m)	1.010 1.287	3.497	1035.477	0.010			
Ambiguity PRN25 L1L2 (cycle)		-0.665		-0.557			
Ambiguity PRN 2 L1L2 (cycle)		-14.131		-14.387			
Ambiguity PRN20 L1L2 (cycle)		1.225		0.662			
Ambiguity PRN 3 L1L2 (cycle)		4.243		3.289			
Ambiguity PRN 1 L1L2 (cycle)		10.134		8.488			
Ambiguity PRN31 L1L2 (cycle)		1.688		0.909			
Ambiguity PRN16 L1L2 (cycle)		-7.440		-7.036			
PRNS#	25	2	20	3	1	31	16
Azimuth (degree)	82.11	336.46	248.58	185.84	315.94	205.95	10.88
Elevation (degree)	40.26	50.52	16.93	70.80	40.28	37.44	43.08
Tropospheric Delay (m)	3.69	3.09	8.10	2.53	3.69	3.92	3.49
Ionospheric Delay (m)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Relativity Effect (m)	-6.94	4.47	1.61	-1.23	-2.40	-7.70	0.09
Sagnac Effect (m)	-24.66	8.23	31.58	1.01	17.33	11.36	-4.45
Sat Clk Correction (m)	14590.62	-47126.33	-63943.80	9303.79	88977.78	102612.93	17352.37
Rcv Clock Correction (m)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Earth Tide Correction (cm)	-2.05	-7.51	-3.80	-5.33	-7.49	-3.06	-6.04
Range Correction (m)	14618.52	-47142.20	-63985.12	9301.43	88959.10	102605.31	17353.18
Phase Windup Correction (cm)	1.91	2.46	1.93	2.56	2.48	2.12	2.14
Misclosure P1+L1 (m)	21.73	21.01	22.61	21.30	20.45	20.66	21.18
Residual P1+L1 (m)	0.00	0.01	0.24	0.02	-0.05	-0.08	-0.00
Misclosure P2+L2 (m)	21.74	21.02	22.62	21.30	20.45	20.66	21.18
Residual P2+L2 (m)	-0.00	-0.01	-0.15	-0.01	0.03	0.04	-0.00
Misclosure Phase (cm)	2173.37	2101.32	2261.46	2129.78	2045.01	2065.96	2118.02
Residual Phase (cm)	-0.22	-0.22	-0.15	-0.22	-0.24	-0.24	-0.22
END OF EPOCH (GPS / UTC)	87330.0	2003 7 28 0 15 30.0					

Figure 12.2: Processing information for one epoch.

The first line displays the GPS time (in seconds) and UTC (year, month, day, hour, minute, second). The second and third lines list the estimates of the unknown parameters. On the second line, the latitude, longitude, and height are shown in DDMMSS.SSSSS format, followed by the estimated receiver clock offset (in metres) and the zenith tropospheric delay (in metres). On the third line, the latitude, longitude, and height coordinates from the second line have been converted to Cartesian coordinates, in metres. Additional lines may be output depending on the parameters that are specified before processing. For example, an additional line will appear with velocity estimates when velocity estimation is enabled.

The number of satellites used for computations, and the total number of satellites visible to the receiver at the current epoch, are shown on line 4. Line 5 lists various dilutions of precision.

Line 6 lists the standard deviations associated with the unknown parameters: latitude STD, longitude STD, height STD, receiver clock STD, and zenith tropospheric delay STD, all in metres.

Float ambiguity information is displayed for each satellite on the following several lines for L1 and L2. In the Traditional Model in PPP mode, a combined ambiguity term is shown, since the model cannot separate the ambiguities on L1 and L2. In Figure 12.2 above, the UoC Model was used in PPP mode (as listed under the 'Ambiguity Model' parameter in the header of the P^3 LOG file shown in Figure 12.1). Since ambiguities on L1 and L2 can be separated in this model, both ambiguity values are shown for each satellite. Equations for the estimation of the combined ambiguity term in the Traditional Model and the separate L1 and L2 ambiguities in the UoC Model are provided in Appendix C.

Many other parameters are listed for each tracked satellite. These parameters are listed in Table 12.1 with a short description of each. Note that star characters are shown for some of these parameters for specific satellites. This occurs when the satellite was not used for computations because of any of the following reasons:

- **`ele cut`** – satellite elevation angle was below the elevation cutoff angle specified by the user
- **`QC fail`** – satellite failed a quality control check
- **`no preci`** – no precise data was available for the satellite
- **`outlier`** – satellite observations are outliers
- **`no observ`** – satellite has incomplete observations
- **`exclusive`** – satellite was excluded by the user

Table 12.1: Additional parameter listings one processed epoch.

Parameter	Description	Available Modes
Azimuth (degree)	Satellite azimuth.	All
Elevation (degree)	Elevation angle of the satellite.	All
Tropospheric Delay (m)	Slant range tropospheric delay, obtained by applying a mapping function to the modeled or estimated zenith troposphere delay.	All
Ionospheric Delay (m)	Slant range ionospheric delay, computed only when L1 code is used in SPP mode in the presence of ionospheric parameters in the navigation file. For all other modes, including L1 & L2 in SPP mode, as well as Traditional and UoC Models in PPP mode, ionospheric-free combinations are formed which eliminate the effect of the ionosphere. The ionospheric delay will be zero for all satellites in these modes.	All
Relativity Effect (m)	Special and general relativistic effects due to the relative velocity of the satellite and the gravity field of the Earth, respectively.	All
Sagnac Effect (m)	Correction due to the Earth's rotation as the signal is transmitted from the satellite to the receiver.	All
Sat Clk Correction (m)	Satellite clock correction. When broadcast data is used, the satellite clock correction is computed from coefficients contained in the navigation file and interpolated for the specific epoch. Similarly, when precise clock data is used, the satellite clock correction is obtained from either the 15 minute SP3 file or the 5 minute CLK file and interpolated for the specific epoch. Finally, when real-time clock corrections are applied to broadcast data contained in the navigation message, the satellite clock correction is simply that correction interpolated for the specific epoch.	All

Rcv Clock Correction (m)	Receiver clock correction.	All
Earth Tide Correction (m)	Correction based on the fact that the "solid" Earth is in fact pliable enough to respond to the same gravitational forces that generate ocean tides. The resulting periodical vertical and horizontal site displacements need to be corrected.	All
Range Correction (m)	Sum of all corrections. Note the signs of the various corrections, shown in the Range Correction equation below. $Range\ Correction = -TD - ID - RE - SE + SatC + RcvC + ET$ Where: *TD* – Tropospheric Delay (m) *ID* – Ionospheric Delay (m) *RE* – Relativity Effect (m) *SE* – Sagnac Effect (m) *SatC* – Sat Clk Correction (m) *RcvC* – Rcv Clock Correction (m) *ET* – Earth Tide Correction (m)	All
Phase Windup Correction (m)	Correction based on the mutual orientation of satellite and receiver antennas. A rotation of either receiver or satellite antenna around its bore axis will change the carrier-phase up to one cycle. This correction is only applied to phase observations, and is therefore not included in the Range Correction described above.	PPP only
Misclosure Code (m)	Code misclosure when using the L1 frequency in SPP mode, or misclosure on ionospheric-free code combination when using L1 & L2 frequencies in SPP mode, or the Traditional Model in PPP mode.	SPP, PPP for Traditional Model only
Residual Code (m)	Code residual when using the L1 frequency in SPP mode, or residual on ionospheric-free code combination when using L1 & L2 frequencies in SPP mode, or the Traditional Model in PPP mode.	SPP, PPP for Traditional Model only
Misclosure Phase (cm)	Misclosure on ionospheric-free phase combination in the Traditional and UoC Models.	PPP only
Residual Phase (cm)	Residual on ionospheric-free phase combination in the Traditional and UoC Models.	PPP only
Misclosure P1+L1 (m)	Misclosure on P1 and L1 ionospheric-free combination used in the UoC Model.	PPP for UoC Model only
Residual P1+L1 (m)	Residual on P1 and L1 ionospheric-free combination used in the UoC Model.	PPP for UoC Model only
Misclosure P2+L2 (m)	Misclosure on P2 and L2 ionospheric-free combination used in the UoC Model.	PPP for UoC Model only
Residual P2+L2 (m)	Residual on P2 and L2 ionospheric-free combination used in the UoC Model.	PPP for UoC Model only

13. Report File

The *REPORT* button allows users to output a report file (in ASCII format) containing values associated with processing. The path and name of this output file, the datum with respect to which output coordinates will be reported, and the information that will appear in the output file, can all be specified. The window associated with the *REPORT* button is shown in Figure 13.1.

Note that the report file is based only on the LOG file that is specified under the 'Log File Path and Name' panel of the *Settings* tab in the **Setup** window. The report file is not related to the current parameters in the various dialogs. The LOG file should not be modified in any way, because this may impact output results (either the report file, described in this section, or graphs, described in Section 14).

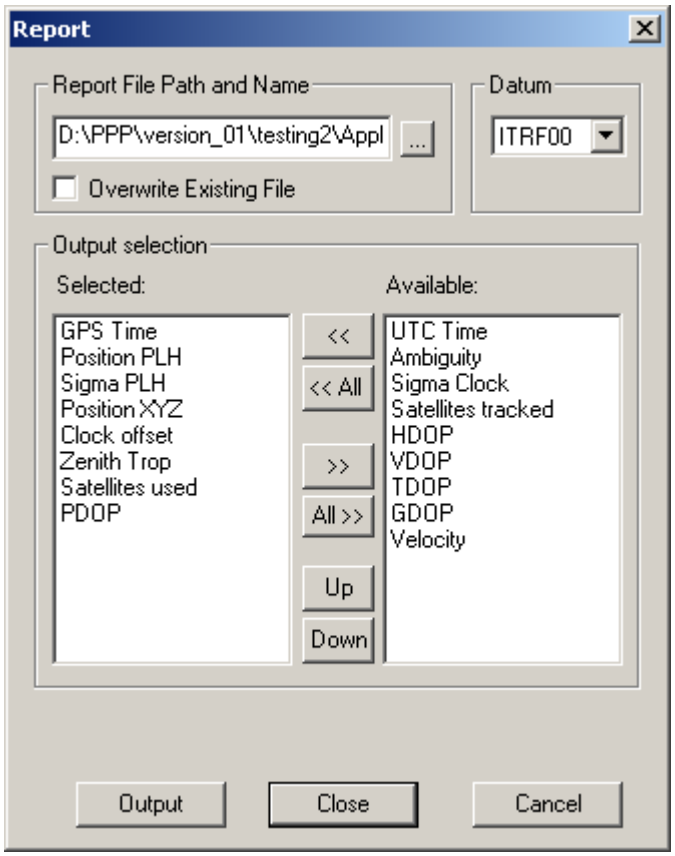


Figure 13.1: Report window.

REPORT FILE PATH AND NAME

In 'Report File Path and Name', either type the path and name where you want to place the REPORT file, or use the browse button to specify the path.

OVERWRITE EXISTING FILE

The OVERWRITE EXISTING FILE option can be used to automatically overwrite the file if it already exists. This option has been implemented so that the user will not accidentally overwrite an existing file with new output information.

When this option is left unchecked and the file that is specified in the 'Report File Path and Name' panel already exists, a message will appear asking the user if they want to overwrite the existing file. At that time, the user can click YES, and the file will be overwritten with output information from the LOG file currently selected in the 'Log File Path and Name' panel of the *Settings* tab in the **Setup** window. If the user clicks NO, a dialog will appear allowing the user to specify an alternate path and name for the report file.

Alternatively, if the OVERWRITE EXISTING FILE option is checked and the file that is specified in the 'Report File Path and Name' panel already exists, the existing file will be overwritten with output information from the LOG file currently selected in the 'Log File Path and Name' panel of the *Settings* tab in the **Setup** window without alerting the user that the report file already exists.

DATUM

Under the DATUM parameter, select WGS84, ITRF00, or NAD83. Coordinate values in the output file will be with respect to the specified datum. Note that there are no official transformation parameters between WGS84 and ITRF00. As such, they are considered to be the same in P^3.

SELECTING ITEMS FOR OUTPUT

The 'Output Selection' portion of the window allows users to select the various types of information to be output to the REPORT file. All available items for output are listed in the left hand portion of the panel, under SELECTED, and the right hand portion of the panel, under AVAILABLE. Use the arrow buttons to transfer the various items between the two windows, until all of the items that are to be in the REPORT file are in the SELECTED portion of the panel. Also, double clicking an item in one list (either SELECTED or AVAILABLE) will automatically transfer it to the other list. This may be easier and faster than using the arrow buttons.

Use the UP and DOWN buttons to order the items in the SELECTED portion of the panel in the order that they are to appear in the output file. The first column in the output file will be the top item in the list, the second column will be the second item, and so on.

AVAILABILITY OF VARIOUS ITEMS

Not all of the items are available in all processing modes. For example, the 'Position Error' item is only available in static mode, when a comparison between the computed position and the initial coordinates supplied by the user can be made. Similarly, the 'Ambiguity' item is only available in PPP mode.

OUTPUT BUTTON

Once all of the desired items are in the SELECTED panel, and are ordered as desired, click the *OUTPUT* button to write the file. The file, with the name and path as specified in the 'Report File Path and Name' panel, will be created.

CLOSE BUTTON

If you would like to write the file at a later time, but still preserve the chosen items in the SELECTED portion of the panel in the desired order, simply click the *CLOSE* button. At a later time, you can click the *REPORT* button again, and all of the items previously selected and in the same order as before will appear (as long as the processing mode remains the same).

CANCEL BUTTON

If you do not want to retain the changes you have made to the SELECTED and AVAILABLE lists simply click *CANCEL*.

SAMPLE REPORT FILE

A sample report file is shown in Figure 13.2. GPS time, the position in latitude, longitude and height, the receiver clock offset, the zenith tropospheric delay, the number of satellites used for processing, and the PDOP were all selected and output to the REPORT file. As can be seen in the figure, this file can be easily imported into other programs for further analysis.

GPS Time	Lat(DD MM SS.SS)	Lon(DDD MM SS.SS)	Height(m)	Clock(m)	ZTD(m)	Used	PDOP
518400.0	45 57 20.88489	-78 4 16.92661	200.667	-231.044	2.290	7	2.5
518430.0	45 57 20.90327	-78 4 16.92566	200.701	-230.983	2.290	7	2.5
518460.0	45 57 20.92246	-78 4 16.91894	200.768	-230.950	2.291	7	2.5
518490.0	45 57 20.91942	-78 4 16.92139	200.497	-230.783	2.290	7	2.5
518520.0	45 57 20.90794	-78 4 16.92621	200.307	-230.713	2.290	7	2.5
518550.0	45 57 20.89559	-78 4 16.93200	200.023	-230.578	2.290	7	2.5
518580.0	45 57 20.88258	-78 4 16.93644	199.502	-230.260	2.290	7	2.5
518610.0	45 57 20.88117	-78 4 16.93760	199.340	-230.159	2.290	7	2.5
518640.0	45 57 20.88531	-78 4 16.93818	199.611	-230.352	2.290	7	2.5
518670.0	45 57 20.88954	-78 4 16.93691	200.073	-230.685	2.290	7	2.5
518700.0	45 57 20.89232	-78 4 16.93578	200.367	-230.902	2.291	7	2.5
518730.0	45 57 20.89602	-78 4 16.93424	200.515	-231.003	2.291	7	2.5
518760.0	45 57 20.90049	-78 4 16.93227	200.654	-231.086	2.291	7	2.5
518790.0	45 57 20.90264	-78 4 16.92979	200.219	-230.761	2.291	7	2.5
518820.0	45 57 20.90332	-78 4 16.92901	199.911	-230.537	2.291	7	2.5
518850.0	45 57 20.90398	-78 4 16.93022	199.993	-230.591	2.291	6	2.7
518880.0	45 57 20.90377	-78 4 16.93319	200.145	-230.722	2.291	7	2.5
518910.0	45 57 20.89767	-78 4 16.93500	200.113	-230.730	2.291	7	2.5
518940.0	45 57 20.89808	-78 4 16.93380	199.875	-230.582	2.291	6	3.1
518970.0	45 57 20.89760	-78 4 16.93429	199.792	-230.537	2.291	7	2.5
519000.0	45 57 20.89573	-78 4 16.93532	199.840	-230.595	2.291	7	2.5

Figure 13.2: Report file sample.

14. Graphs

In this section, graphs available in P^3 are described.

Note that all graphs are based only on the LOG file that is currently specified under the 'Log File Path and Name' panel of the *Settings* tab in the **Setup** window. The graphs are not related to the current parameters in the various dialogs. The LOG file should not be modified in any way, because this may impact output results (either graphs, described in this section, or the report file, described in Section 13).

The *DISPLAY* button on the Button bar is used to activate various graphs, and is further described in Section 14.1.

14.1. Displaying Graphs

The *DISPLAY* button allows users to open the Display View, in which various graphs can be examined. This can be done either when processing has run to completion or when the user terminates processing using the *STOP* button. Clicking on Display in the **DISPLAY** menu can also open the Display View.

Note that the graphs cannot be activated when processing is taking place or when it has been temporarily paused. A warning message will appear if the *DISPLAY* button is pressed or if the Display option is accessed in the **DISPLAY** menu during this time.

Note also that a minimum of one hour is always displayed in the graphs. When less than one hour of data is processed, the processed data will be plotted correctly with respect to GPS time, but may appear shifted in the graph.

MOUSE MENU

A second menu is available in the Display View at the right click of the mouse button. This menu is shown on the left in Figure 14.1 and will be referred to as the **MOUSE** menu in the following descriptions.

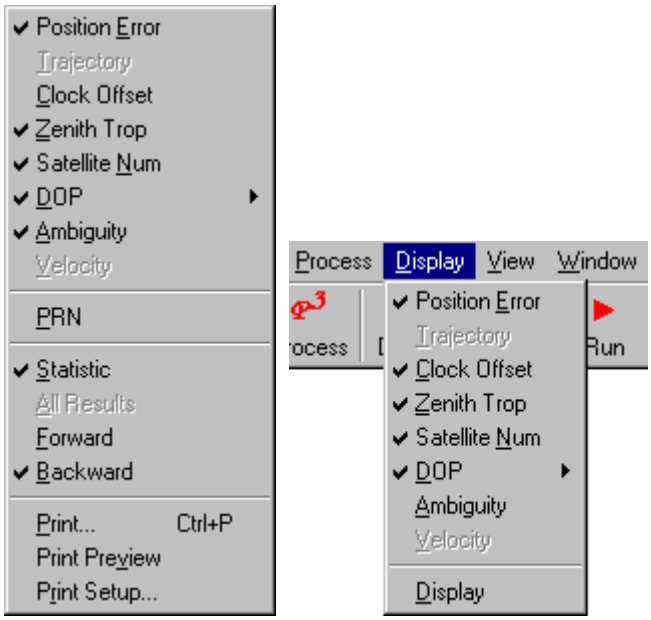


Figure 14.1: MOUSE and **DISPLAY** menus.

The **MOUSE** menu allows users to access some other options associated with the graphs. The top portion of the menu is exactly the same as the one that can be accessed in the **DISPLAY** menu in the Menu bar, as shown in Figure 14.1. The other options are:

- PRN
- Statistic
- All Results
- Forward
- Backward
- Print
- Print Preview
- Print Setup

They will be described in Sections 14.4.1 to 14.4.7 with the graphs for which they are intended, since these options do not apply to all graphs. Because of this, the **MOUSE** menu may change depending on the processing mode. For example, in kinematic mode, the options 'Static' and 'All Results' are not available in the **MOUSE** menu since they are only used in static mode for the **Position Error** graph. Print options accessible from the **MOUSE** menu are available in all processing modes.

14.2. Selecting Between Graphs

The **DISPLAY** menu, besides the mentioned function above that allows users to open the Display View, can also be used to select between the various available graphs. The **MOUSE** menu can also be used for this task.

Only four graphs can be displayed simultaneously in the Display View. Initially, four default graphs are shown when the Display View is opened. To view a graph that is currently not shown, one of the graphs that is shown must first be

disabled before the graph of your choice is enabled. To do this, simply click on the **DISPLAY** menu and select one of the graphs that has a checkmark next to it, disabling that graph. Then, again by clicking on the **DISPLAY** menu, select the graph that you wish to view, thus enabling it in the Display View.

Note that the graph associated with the number of satellites is displayed along with the dilution of precision graphs. In order to deactivate this graph, you will have to disable all active **Dilution of Precision** graphs and the **Number of Satellites** graph.

14.3. Forward and Backward Processing

In post-mission PPP mode, the user can select the BACKWARD PROCESSING option in the post-mission **PPP** window. For certain graphs, the user will have to use the Forward and Backward options in the **MOUSE** menu to toggle between forward and backward processing. This is the case for the **Position Error**, **Kinematic Solution Trajectory**, **Velocity** and **Ambiguity Changes** graphs. Results of both forward and backward processing appear simultaneously for the remaining graphs.

14.4. Graph Types

Available graphs are shown in Table 14.1, along with their associated modes.

Table 14.1: Graphs and their modes.

Graph Type	Mode
Position Error	Static
Kinematic Solution Trajectory	Kinematic
Receiver Clock Offset	All
Zenith Troposphere Correction	All
Number of Satellites	All
Dilutions of Precision	All
Velocity	PPP, Kinematic
Ambiguity Changes	PPP

These graphs are described in Sections 14.4.1 to 14.4.7. A description of printing graphs is provided in Section 14.5.

GPS time, in seconds, is plotted on the horizontal axis of all graphs. Also, all graphs have an associated legend that appears below each graph in order to identify the various plots in the graphs.

14.4.1. Position Error

The **Position Error** graph shows the position error in latitude, longitude and height with respect to the approximate initial coordinates entered by the user. These initial coordinates are input in the **Setup** window under the *Initial Coordinates* tab (see Section 8.3). Because the initial approximate coordinates are used as the true coordinates in this plot, the user should not be too concerned if the error plots do not converge to the horizontal axis, especially if the initial approximates are poor. However, if the software is used for testing purposes and

true coordinates are used as initial coordinates, then the errors should converge to the zero axis.

Errors, in metres, appear on the vertical axis for latitude (plotted in red), longitude (plotted in green) and height (plotted in blue).

Use the 'Forward' and 'Backward' options in the **MOUSE** menu to toggle between forward and backward processing when in post-mission PPP mode. An example **Position Error** graph for forward and backward processing is shown in Figures 14.2 and 14.3, respectively.

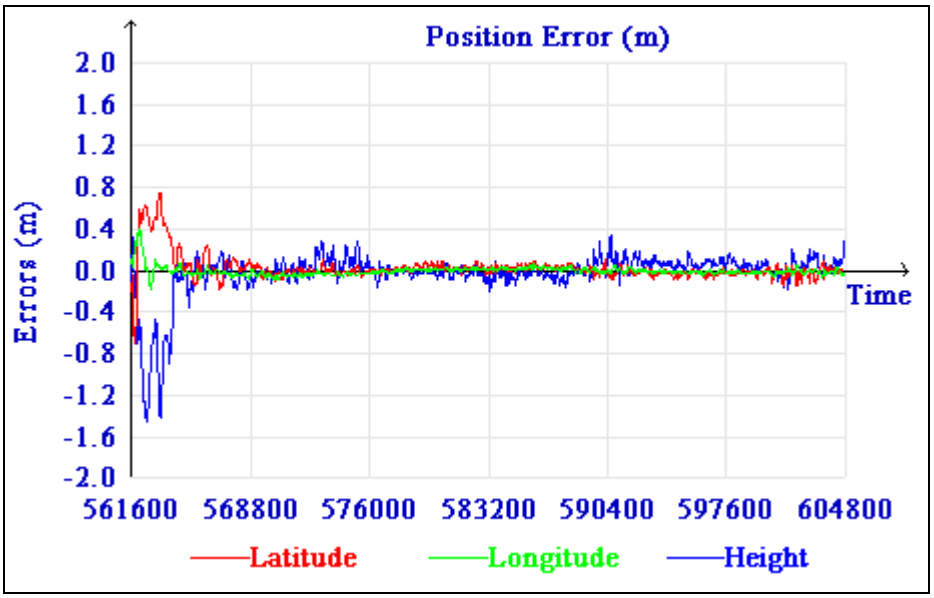


Figure 14.2: Position Error graph for forward processing.

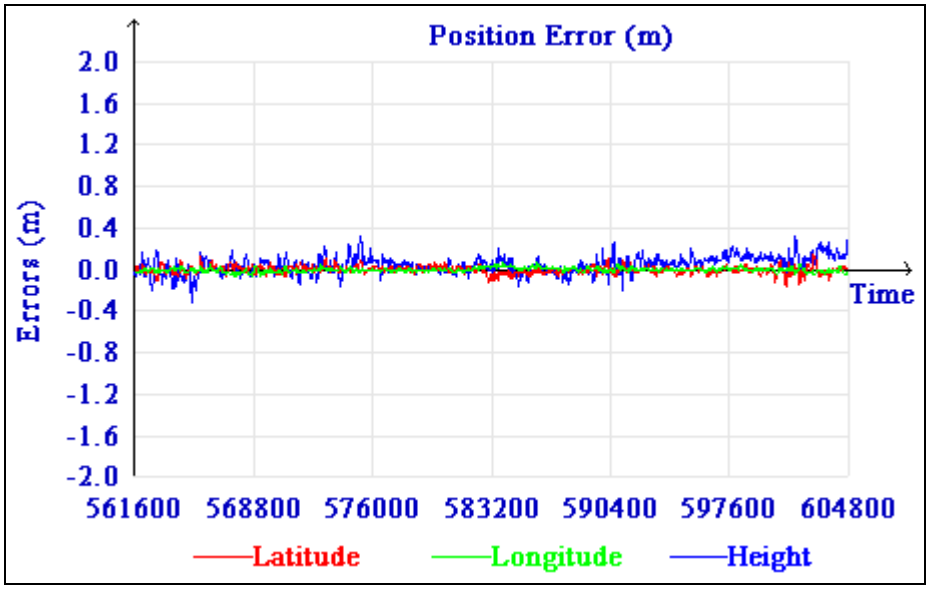


Figure 14.3: Position Error graph for backward processing.

STATISTICS

Position error statistics are available in static mode. These are displayed when the 'Statistic' option is selected in the **MOUSE** menu. The mean, standard deviation and RMS are tabulated for latitude, longitude and height for all data that was processed. These statistics are shown in Figure 14.4.

	Latitude	Longitude	Height
MEAN(m):	-0.1071	0.0044	-1.2227
RMS(m):	0.4033	0.2437	1.2970
STD(m):	0.3990	0.2499	0.4440

Figure 14.4: Position error statistics.

SUBSETTING POSITION ERROR GRAPH AND STATISTICS

To view the statistics associated with a subset portion of the **Position Error** graph, simply drag a window around the desired portion of the graph in the Display view. Only the position error results that fall within the window will be displayed. If position error statistics are enabled (displayed using the 'Statistic' option in the **MOUSE** menu), they will only be for the subset portion currently displayed in the **Position Error** graph.

An example use of this feature is shown in Figures 14.5 and 14.6 below. In Figure 14.5, the position errors associated with forward processing results are shown, along with their corresponding statistics. A window was drawn around the latter two-thirds of the data, and the resulting **Position Error** graph is shown in Figure 14.6 along with its associated statistics. Note that now the statistics refer only to the subset portion. This feature allows users to, for example, obtain the statistics of the results after convergence.

Data subsetting can be applied to either the forward or backward position errors.

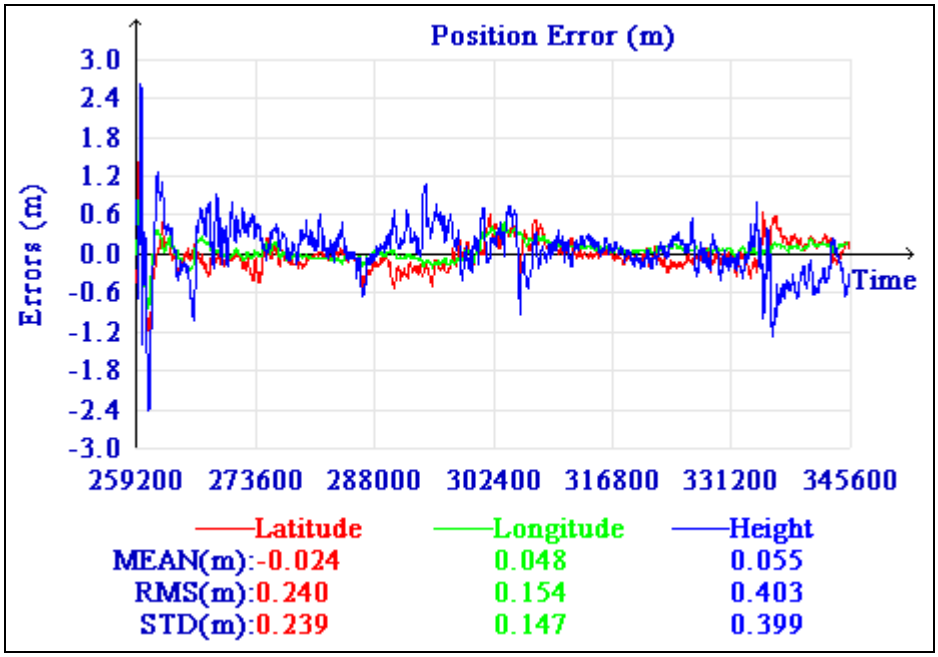


Figure 14.5: **Position Error** graph for all forward processing results.

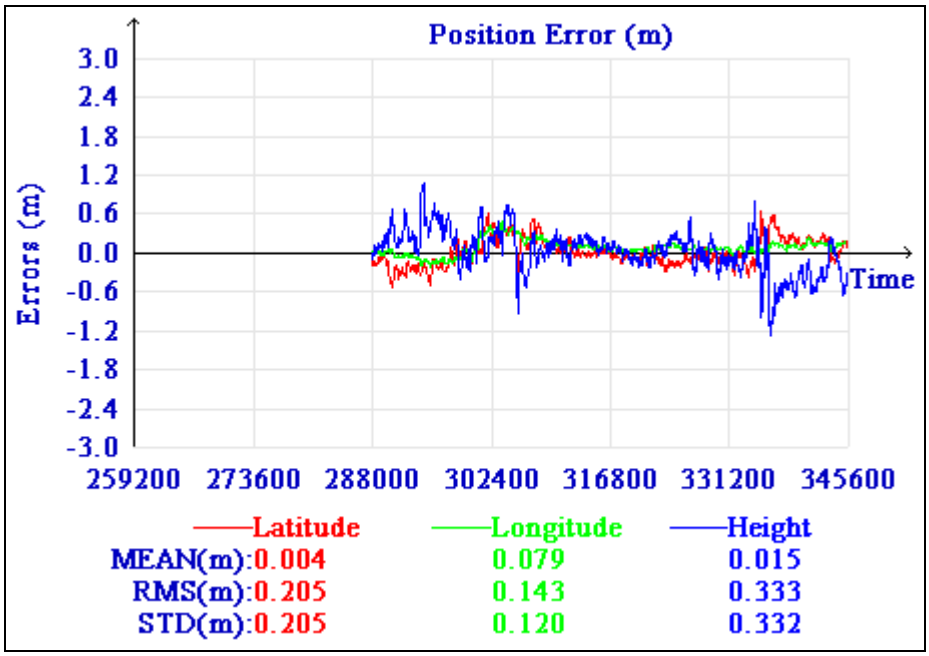


Figure 14.6: **Position Error** graph for a subset portion of forward processing results.

ALL RESULTS

The 'All Results' option in the **MOUSE** menu can be used to restore all position error data for the entire processing period. This option is only available when the user subset the position error results, as shown in Figure 14.6 above. When all results are displayed, as is the case in Figure 14.5, the 'All Results' option is disabled in the **MOUSE** menu.

The 'All Results' option can be applied to either forward or backward position errors.

14.4.2. Kinematic Solution Trajectory

The **Kinematic Solution Trajectory** graph is only available in kinematic mode. This graph shows a trajectory of the receiver's computed position. A sample trajectory is shown in Figure 14.7.

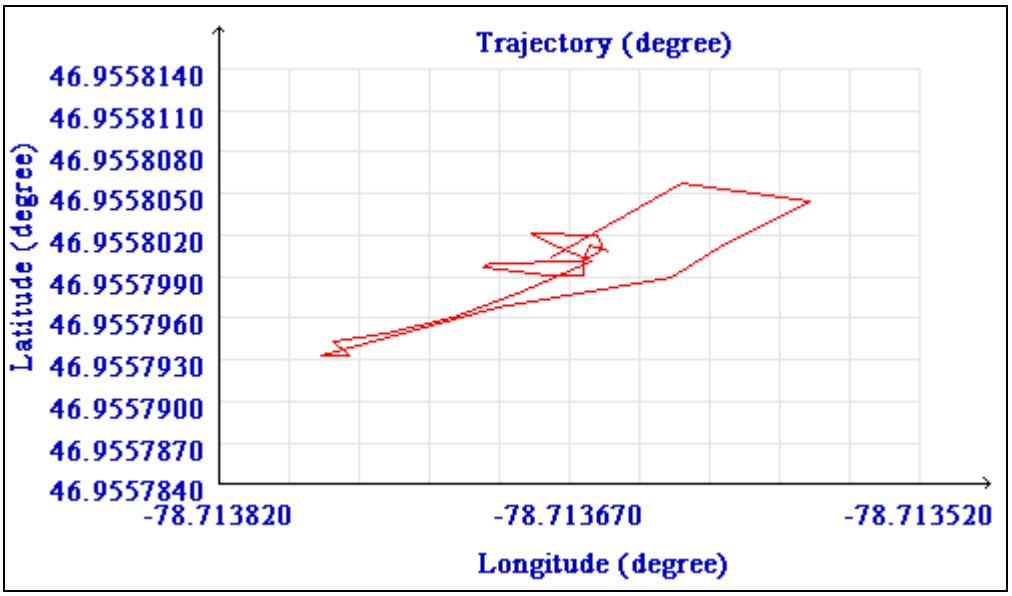


Figure 14.7: Kinematic Solution Trajectory graph.

The latitude is shown on the vertical axis and the longitude on the horizontal axis. Both are in decimal degrees. Use the 'Forward' and 'Backward' options in the **MOUSE** menu to toggle between forward and backward solution trajectories when in post-mission PPP mode.

14.4.3. Receiver Clock Offset

The **Receiver Clock Offset** graph is available in all modes. The clock offset is shown on the vertical axis, in metres. A sample **Receiver Clock Offset** graph is shown in Figure 14.8. In this figure, BACKWARD PROCESSING was not activated. As such, the plot shows the trajectory for forward processing only.

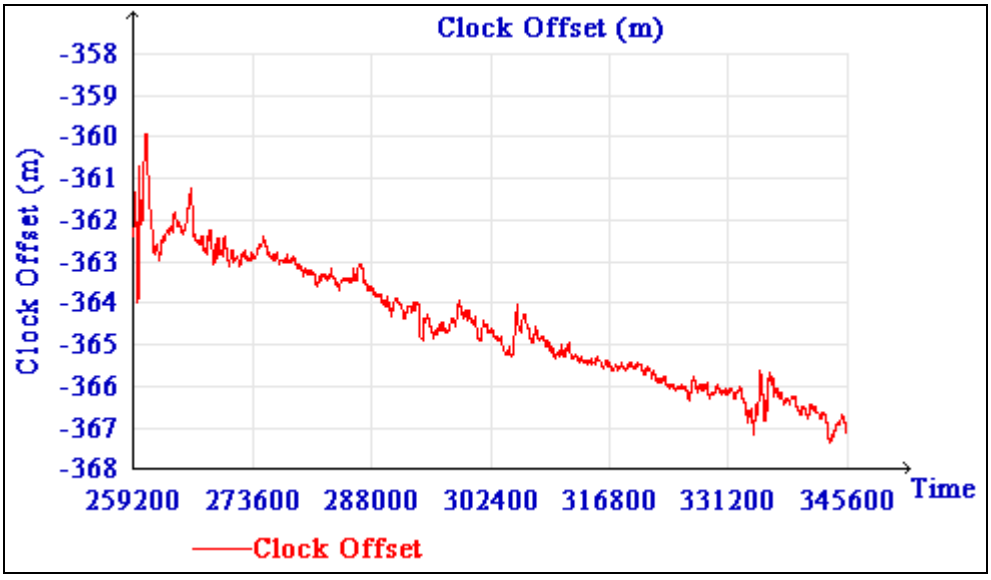


Figure 14.8: Receiver Clock Offset graph.

In post-mission PPP mode, and when BACKWARD PROCESSING has been selected, the receiver clock offset for forward and backward processing will be displayed simultaneously. However, sometimes the estimation of the receiver clock error will be virtually identical in forward and backward processing. In such a case, the backward processing plot may exactly overlay the forward processing plot, making it seem as though only the backward processing plot is shown.

14.4.4. Zenith Troposphere Delay

The **Zenith Troposphere Correction** graph is available in all modes. In SPP mode, or when the user has not selected troposphere estimation in PPP mode, the modeled troposphere correction will be shown. If the user has selected troposphere estimation in PPP mode, the estimated troposphere correction will be shown. Troposphere modeling and estimation are described in Section 10.3.

A sample **Zenith Troposphere Correction** graph is shown in Figure 14.9. PPP processing with troposphere estimation was done to generate this graph. In this figure, BACKWARD PROCESSING was not activated. As such, the plot shows the troposphere correction for forward processing only.

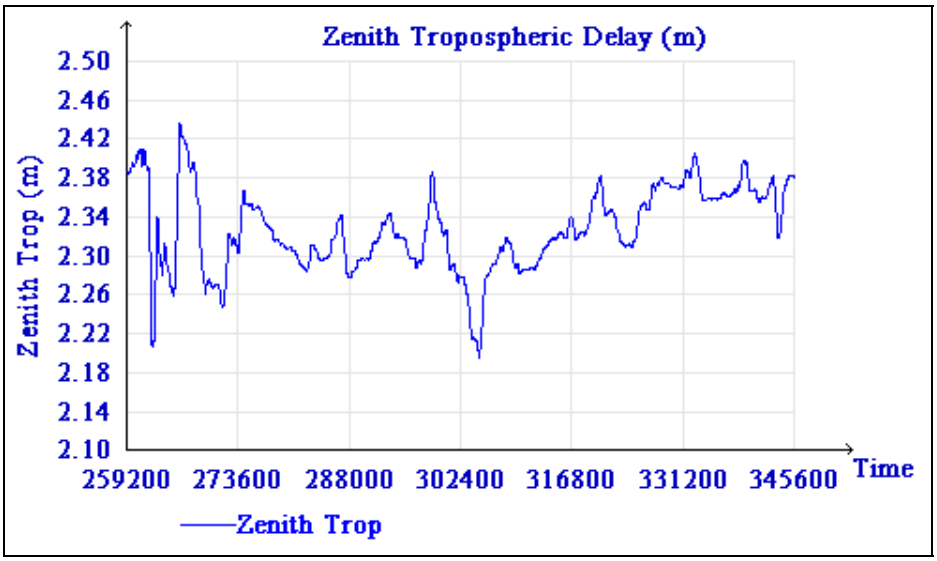


Figure 14.9: **Zenith Troposphere Delay** graph.

In post-mission PPP mode, and when BACKWARD PROCESSING has been selected, the zenith troposphere delay for forward and backward processing will be displayed simultaneously.

14.4.5. Number of Satellites

A graph of the number of satellites that were used for processing is available in all processing modes. A sample graph is shown in Figure 14.10. The number of satellites is shown on the vertical axis. If **Dilution of Precision** graphs are currently enabled, the **Number of Satellites** graph will appear simultaneously in the same figure.

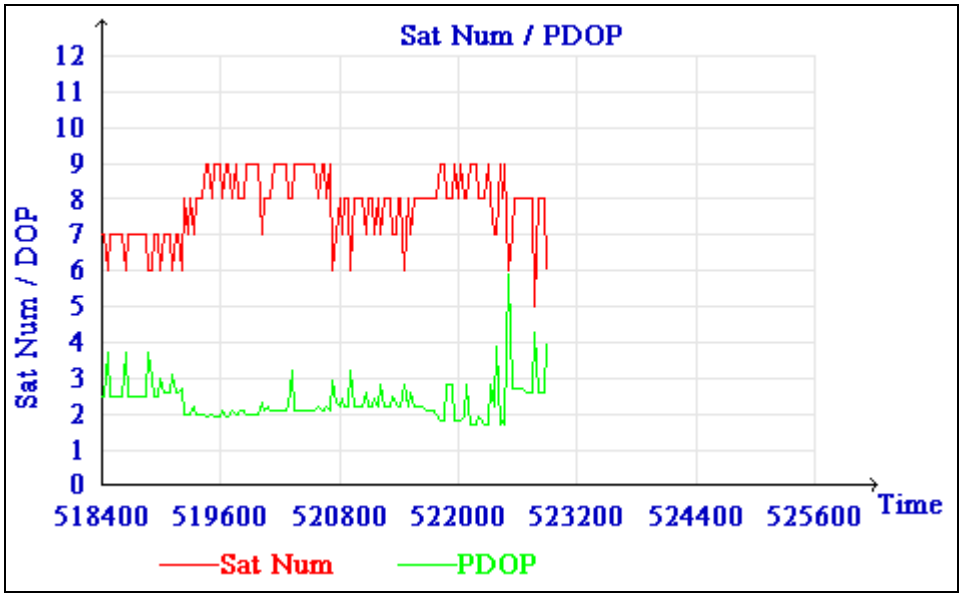


Figure 14.10: **Number of Satellites** and **Dilutions of Precision** graph.

The **Number of Satellites** and **Dilution of Precision** graphs are the same for forward and backward processing since the same data is used to generate them.

14.4.6. Dilutions of Precision

Graphs of various dilutions of precision are available in all processing modes. These graphs, which include **PDOP** (position), **HDOP** (horizontal), **VDOP** (vertical), **TDOP** (time) and **GDOP** (geometric), are shown simultaneously in the **Number of Satellites** graph if it is currently enabled, as shown in Figure 14.10. The DOP number appears on the vertical axis.

The **Number of Satellites** and **Dilution of Precision** graphs are the same for forward and backward processing since the same data is used to generate them.

14.4.7. Velocity

Velocity estimation is only available in PPP mode for kinematic processing. A graph of the velocity of a receiver mounted on an aircraft is shown in Figure 14.11. The velocity, in metres per second, is shown on the vertical axis. The velocities in the northing (plotted in red), easting (plotted in green) and up (plotted in blue) components are plotted.

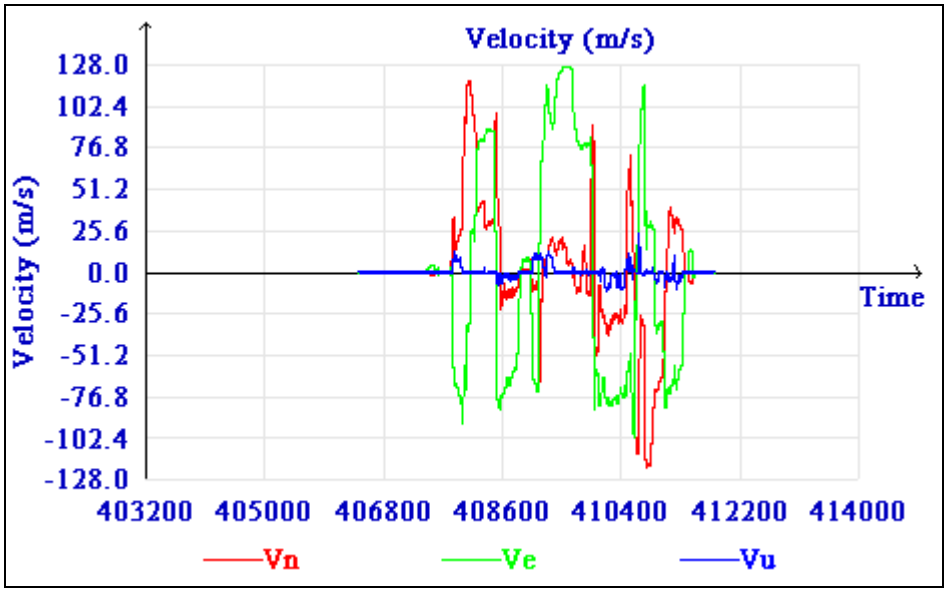


Figure 14.11: Velocity graph.

Use the 'Forward' and 'Backward' options in the **MOUSE** menu to toggle between forward and backward velocity estimations when in post-mission PPP mode.

14.4.8. Ambiguity Changes

A graph of ambiguity changes is available in PPP mode when either the Traditional or UoC Model is used. Use the 'Forward' and 'Backward' options in the **MOUSE** menu to toggle between forward and backward ambiguity changes when in post-mission PPP mode.

COMPUTING AMBIGUITY CHANGES

At the first epoch in which computations can be made (i.e.: there were a sufficient number of satellites, the solution converged, no matrix was singular, etc.), ambiguities are estimated from ionospheric-free code and carrier phase combinations. In the Traditional Model, a combined ambiguity term is computed since the ambiguities on L1 and L2 cannot be separated. In the UoC Model, which allows for separate estimation of the L1 and L2 ambiguities, both are estimated as float values. Equations for the estimation of the combined ambiguity term in the Traditional Model and the separate L1 and L2 ambiguities in the UoC Model are provided in Appendix C.

Once computed, the estimated ambiguity quantities are used as approximates in the least-squares process, which itself estimates the ambiguity quantities for each satellite at each epoch along with the other unknowns. Differences between the new ambiguity values computed at each epoch and the initial ambiguity values computed in the first epoch are graphed for each satellite.

Whenever the difference between the computed ambiguity and the initial ambiguity exceeds 5 m, the initial ambiguity is made equal to the computed ambiguity at that processing epoch. This is done to ensure a good scale for viewing the ambiguity changes. For example, if a cycle slip occurs, the difference between the computed ambiguity and the initial ambiguity may be very large. By resetting the initial ambiguity so that the difference is always below 5 m, a good representation of the ambiguity changes is guaranteed. This resetting procedure is shown in Figure 14.12.

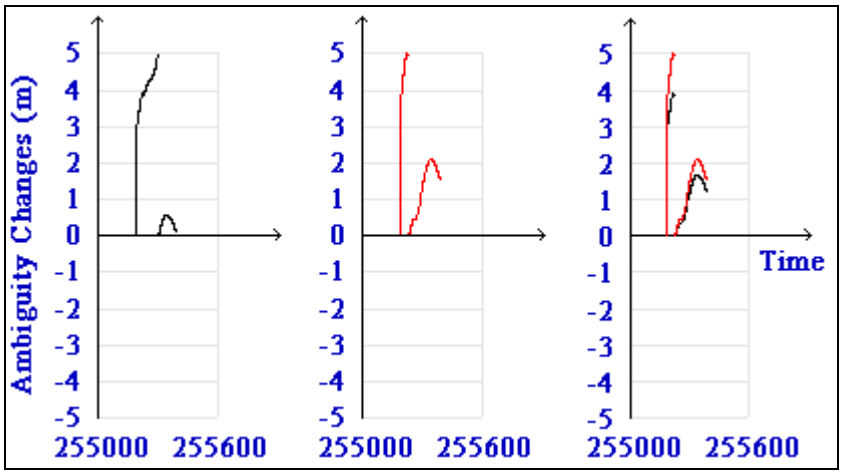


Figure 14.12: **Ambiguity Changes** graphs for L1, L2 and L1 & L2.

As can be seen from Figure 14.12 above, the difference between the computed ambiguity and the initial ambiguity exceeds 5 m for both L1 (left graph) and L2 (middle graph). The initial value is reset at that point, and the ambiguity computed at later processing epochs is differenced with respect to the new initial value.

When displaying the ambiguity changes for L1 & L2 (right graph – L1 shown in black, L2 shown in red), the initial value is reset according to when L2 exceeds 5 m. It can be seen that the L2 ambiguity change exceeds 5 m faster than the L1 ambiguity change. However, both are truncated at the same time when L1 & L2 are plotted together.

TRADITIONAL MODEL

As mentioned above, a combined ambiguity term is computed for the Traditional Model. The difference between this ambiguity term as computed in each epoch and the initial ambiguity term can be plotted in the Display view, as shown in Figure 14.13.

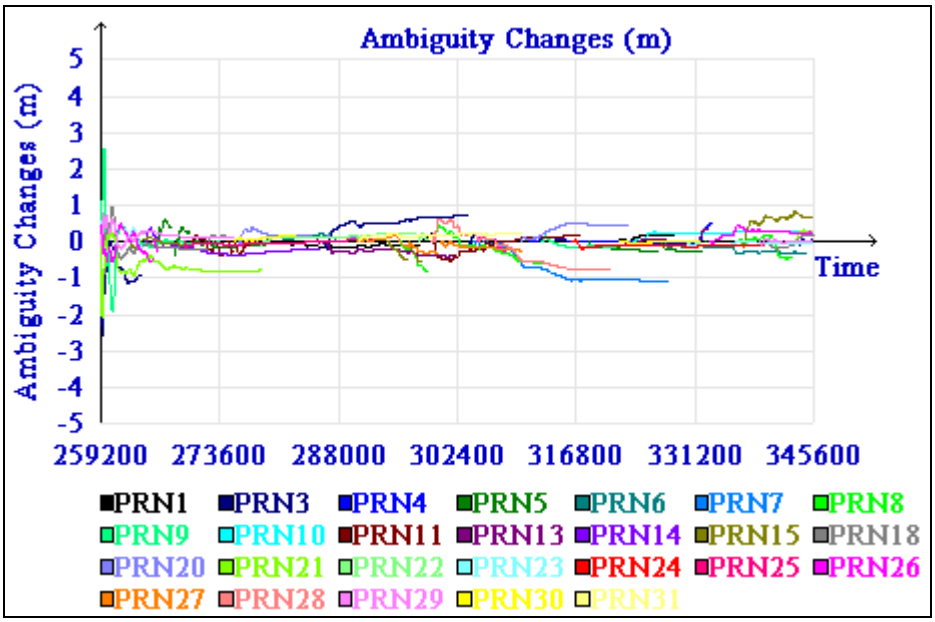


Figure 14.13: **Ambiguity Changes** graph for the Traditional Model.

The PRN option in the **MOUSE** menu can be used to select specific satellites for which the user wants to view ambiguity information. This is described below under the 'PRN Option' heading.

UoC MODEL

In the UoC Model, ambiguities are computed for L1 and L2 separately. The user can display L1 ambiguities only, L2 ambiguities only, or both L1 and L2 ambiguities. When L1 or L2 ambiguities are displayed separately, the resulting graph is similar to Figure 14.13. However, when both L1 and L2 ambiguities are shown, each box next to the PRN in the legend is split horizontally in two. The upper colour is used for the L1 ambiguity, and the lower for the L2 ambiguity, as shown in Figure 14.14.

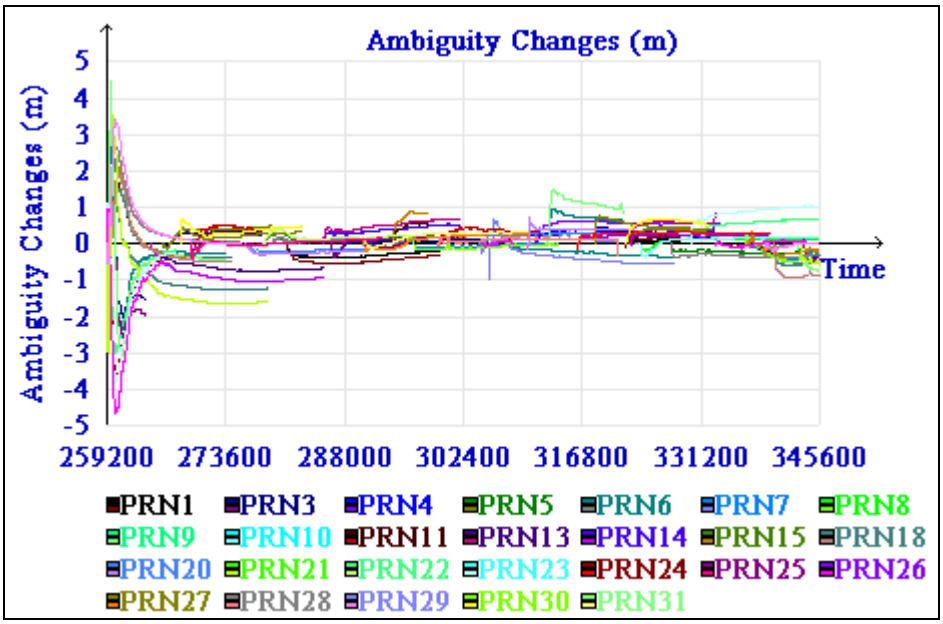


Figure 14.14: Ambiguity Changes graph for the UoC Model for L1 & L2.

The PRN option in the **MOUSE** menu can be used to select specific satellites for which the user wants to view ambiguity information. This is described below under the 'PRN Option' heading.

PRN OPTION

The PRN option brings up the **Show Ambiguity** window which allows users to select the satellites for which they want to view ambiguity information. Additionally, when processing using the UoC Model, the selection between viewing L1, L2, or L1 & L2 ambiguities is also available in this window, which is shown in Figure 14.15.

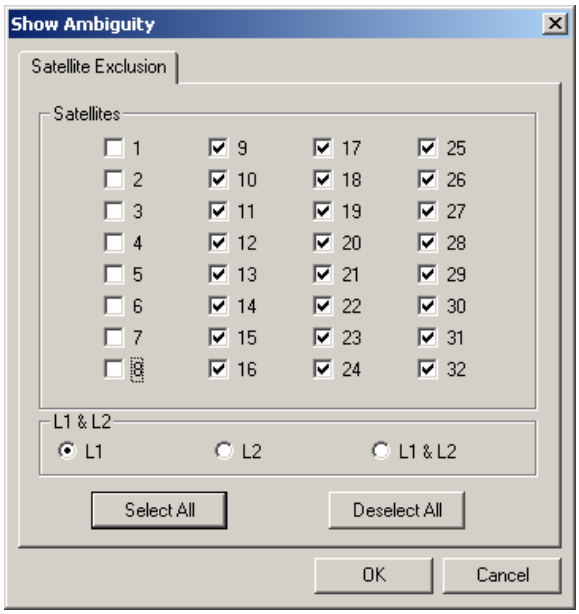


Figure 14.15: Show Ambiguity window.

Satellite selection is based on selecting satellites for which the user **does not** want to view ambiguity information. For example, in Figure 14.15 above, ambiguity information will only be shown for satellites 1-8. The remaining satellites have been selected, indicating that ambiguity information for these satellites will not be shown. Use the *SELECT ALL* and *DESELECT ALL* buttons to select all the satellites and select none of the satellites, respectively. Note that when all satellites have been selected, nothing will be shown in the **Ambiguity Changes** graph.

In the Traditional Model, the lower panel containing choices for L1, L2, and L1 & L2 does not appear since only combined ambiguity values are possible when this model is used. This panel appears only for the UoC Model, as shown in Figure 14.15, allowing users to select between the three options.

14.5. Printing Graphs

The **MOUSE** menu contains three print-related options, as shown in Figure 14.1. These are Print, Print Preview and Print Setup. The functions and windows associated with each should be familiar to most Windows® users. However, a brief description of each is provided.

14.5.1. Print

Selecting the Print option or clicking Ctrl-P brings up the window shown in Figure 14.16.

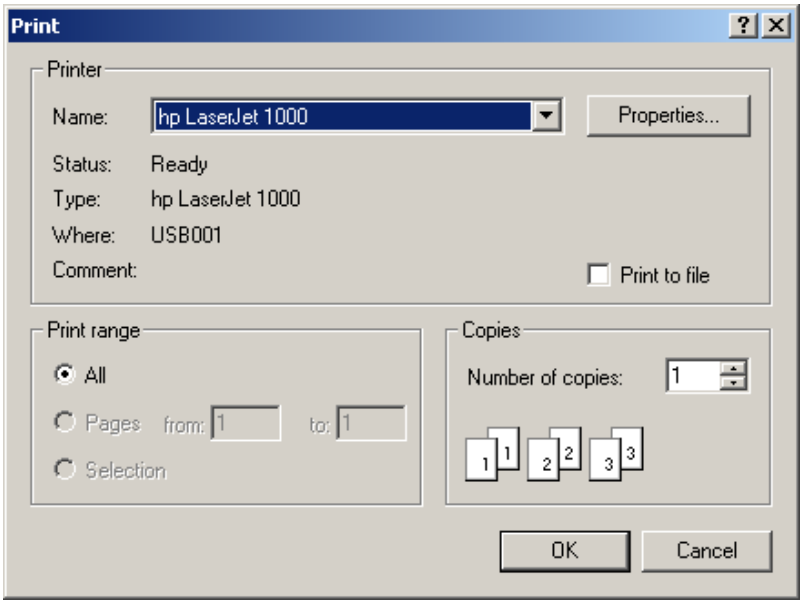


Figure 14.16: Print window.

PRINTER SELECTION

Under the 'Printer' panel, in the upper portion of the **Print** window, the user can select the name of the printer with which they want to print.

PROPERTIES AND OTHER OPTIONS

Printer properties can be accessed by clicking on the *PROPERTIES* button. These properties are not related to P^3 software, and are therefore not discussed here. Other options in Figure 14.16 should be familiar to users.

OK

Clicking on *OK* will send the Display View to the printer for printing, either in portrait or landscape format (as specified in the **Print Setup** window described in Section 14.5.3).

CANCEL

Clicking on *CANCEL* will close the **Print** window without sending anything to the printer.

14.5.2. Print Preview

This option should also be familiar to users. It allows users to see how the Display View will be printed. The portrait preview is shown in Figure 14.17, and the landscape preview is shown in Figure 14.18. The option to print in portrait or landscape format is available in the **Print Setup** window, described in Section 14.5.3.

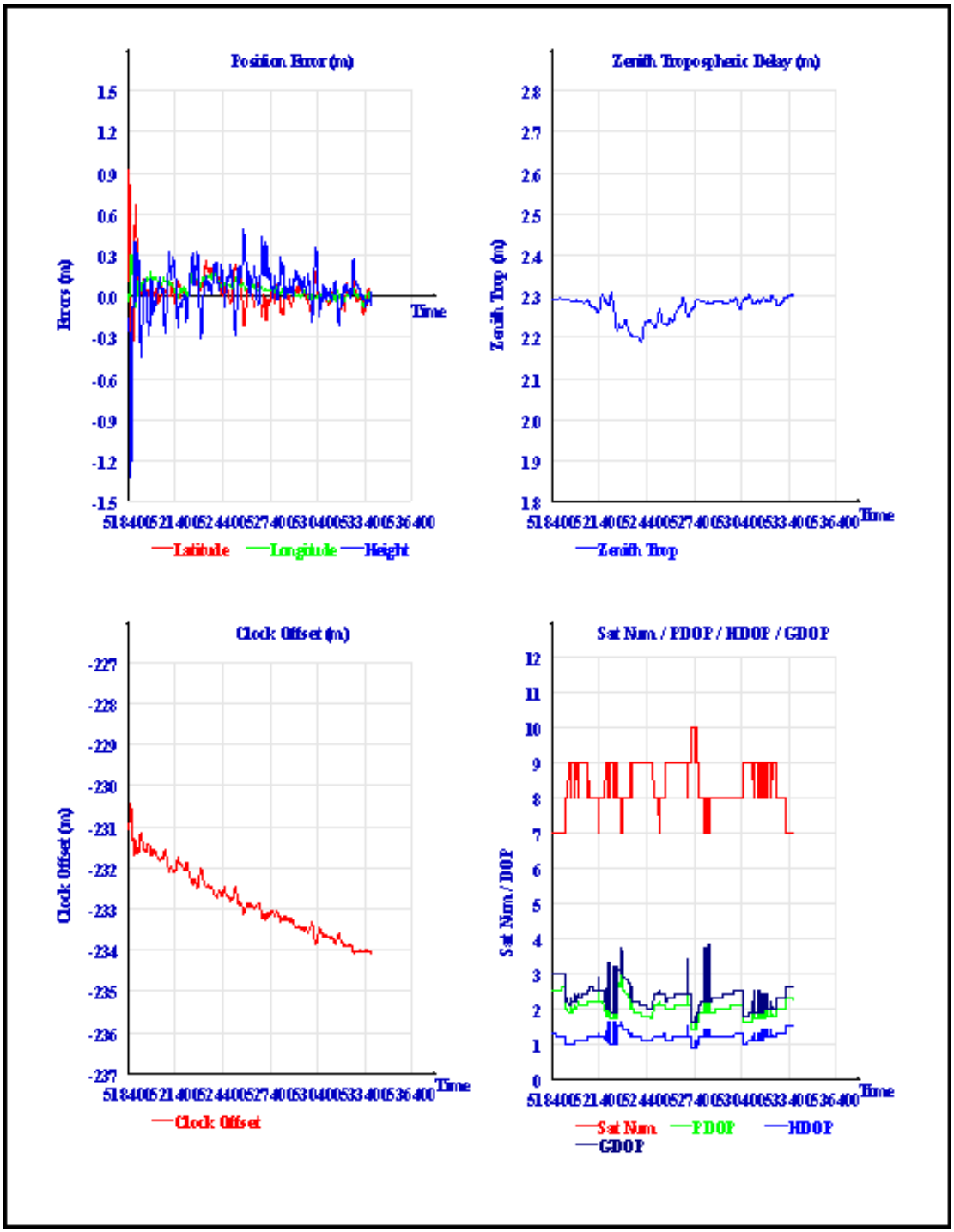


Figure 14.17: Portrait preview window.

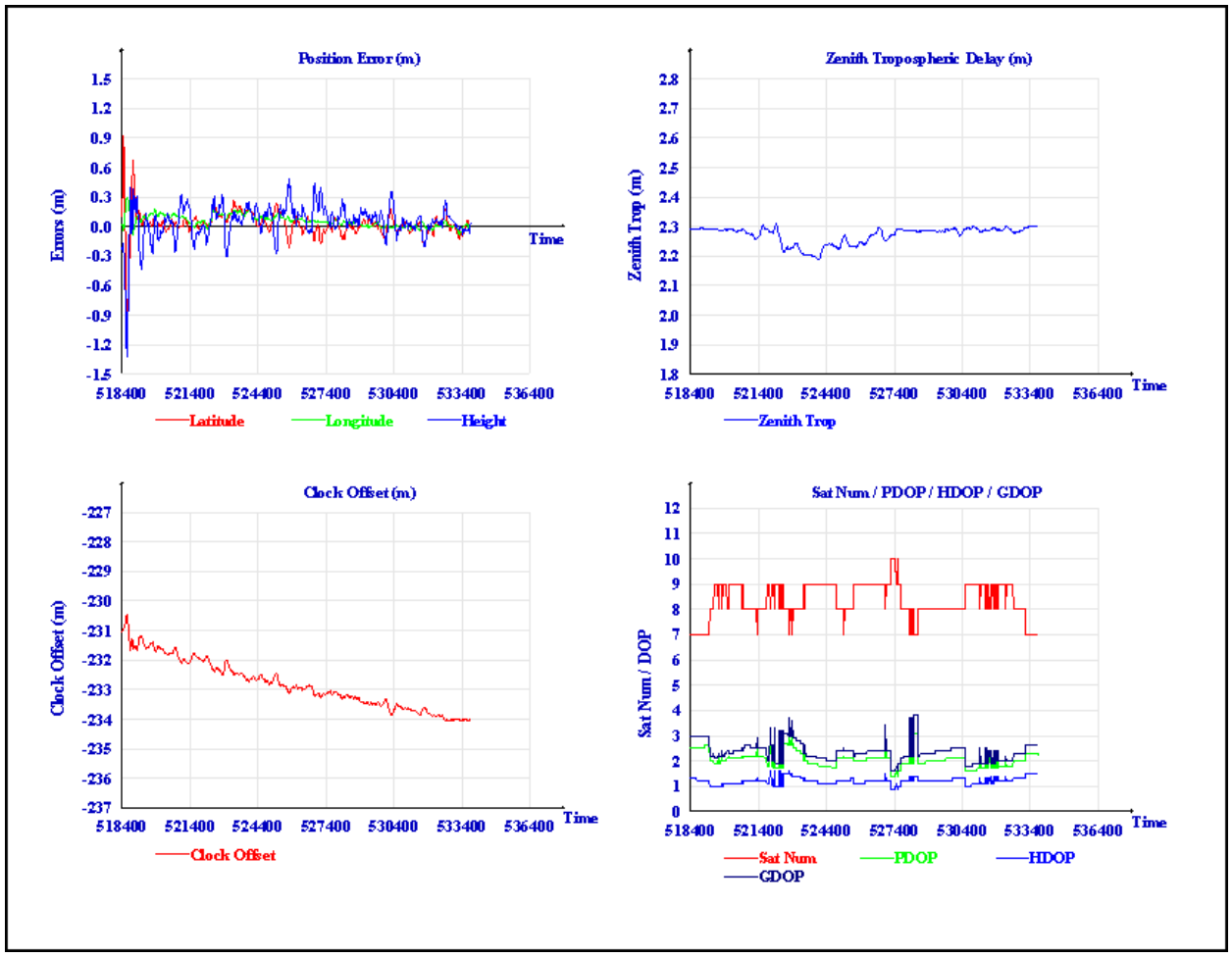


Figure 14.18: Landscape preview window.

PRINT BUTTON

The *PRINT* button in 'Print Preview' mode will print the Display View as shown in the preview window. Note that pressing this button does not bring up the **Print** window shown in Figure 14.16. If the user wants to select options within this window, they should first close the preview screen using the *CLOSE* button (described below), and then open the **Print** window in the **MOUSE** menu. The *PRINT* button in the preview window will use the current options that exist in the **Print** window to print.

ZOOMING IN AND OUT BUTTONS

The *ZOOM IN* and *ZOOM OUT* buttons can be used to zoom in or zoom out of the page, respectively.

CLOSE BUTTON

The *CLOSE* button will close the preview window without printing and return to the Display View.

14.5.3. Print Setup

The Print Setup option allows the user to specify some other options associated with printing, as shown in Figure 14.19.

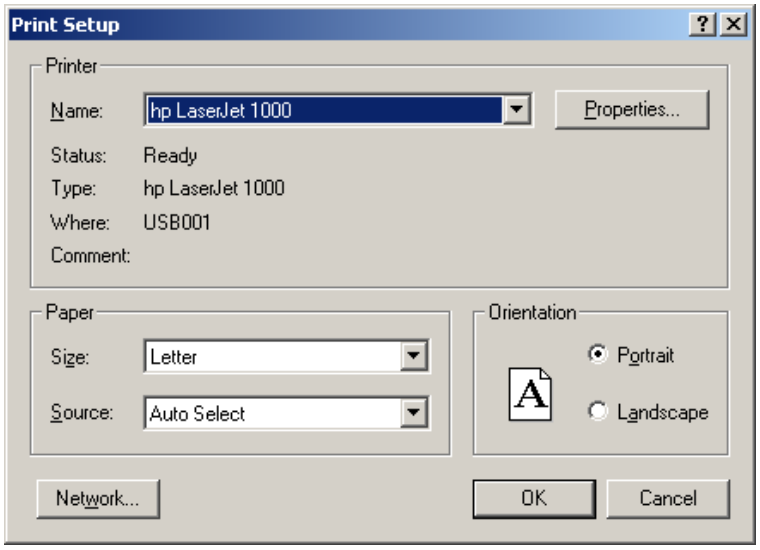


Figure 14.19: Print Setup window.

PRINTER SELECTION

Under the 'Printer' panel, in the upper portion of the **Print Setup** window, the user can select the name of the printer with which they want to print.

PROPERTIES AND OTHER OPTIONS

Printer properties can be accessed by clicking on the *PROPERTIES* button. These properties are not related to P^3 software, and are therefore not discussed here.

SIZE AND SOURCE

The user can also select the paper size and its source from the two drop down lists.

ORIENTATION

The user can select the orientation of the Display View on the page: either portrait or landscape. These two orientations are shown in Section 14.5.2 in Figures 14.17 and 14.18, respectively.

OK

The *OK* button will retain settings as they appear in the **Print Setup** window.

CANCEL

The *CANCEL* button will not preserve any changes that were made to the parameters in the **Print Setup** window.

Appendix A: P³ Parameters and Default/Suggested Values

Table A.1 lists all parameters available in P³ in alphabetical order. The type of value expected for each parameter, a range of acceptable values, units, as well as default and suggested values are also provided. Finally, access to the parameters (i.e.: the windows in which the parameters can be specified) is provided in the last column. 'B' refers to parameter access using the various buttons in the Button bar, and 'M' refers to parameter access using the menu options in the Menu bar. Superscripts are used to number different methods for accessing the same parameter using either the Button bar or the Menu bar. For example, the 'Antenna Type' parameter can be accessed using the Button bar by clicking the *SETUP* button and then clicking on the *Antenna* tab. To access the parameter using the Menu bar, the user can click on the **SETUP** menu, select **SETUP** and then click on the *Antenna* tab in the window that appears. The second method for accessing this parameter using the Menu bar involves clicking on the **SETUP** menu and directly selecting **ANTENNA.** Since the parameter can be accessed using the Menu bar in two ways, each method is preceded by a superscript indicating the method number.

The 'Initial STD' and 'Spectral Density' parameters are entered using two numbers: a float value and a base 10 exponent value (i.e.: 1.5e-2). As such, the entries for these parameters are split in two in the following table. In the example, the float value would be 1.5, and the base 10 exponent value would be -2.

Parameters that require the user to specify a file path and name are not listed in the table. The files that can be specified are: observation file, broadcast ephemeris file, precise ephemeris file, precise clock file, P³ LOG file, P³ report file and IGS PCV file. All file parameters are blank by default.

Table A.1: P³ parameters.

Parameter Name	Type	Range	Units	Default / Suggested Value	Access
Ambiguity (Initial STD)	Float	Min.: 0 Max.: 10	m	1e2/1e2 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Ambiguity (Spectral Density)	Float	Min.: 0 Max.: 10	m^2/s	0e0/0e0 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Antenna Type	Text string			[blank]/NA	**B:** *SETUP* button, *Antenna* tab. **M: [1]SETUP | SETUP**, *Antenna* tab or **[2]SETUP | ANTENNA.**
Antenna Vendor	Text string			[blank]/NA	**B:** *SETUP* button, *Antenna* tab. **M: [1]SETUP | SETUP**, *Antenna* tab or **[2]SETUP | ANTENNA.**
ARP to APC (east)	Float	Min.: -10 Max.: 10	m	0/NA	**B:** *SETUP* button, *Antenna* tab. **M: [1]SETUP | SETUP,** *Antenna* tab or **[2]SETUP | ANTENNA.**
ARP to APC (north)	Float	Min.: -10 Max.: 10	m	0/NA	**B:** *SETUP* button, *Antenna* tab. **M: [1]SETUP | SETUP,** *Antenna* tab or **[2]SETUP | ANTENNA.**
ARP to APC (height)	Float	Min.: -10 Max.: 10	m	0/NA	**B:** *SETUP* button, *Antenna* tab. **M: [1]SETUP | SETUP,** *Antenna* tab or **[2]SETUP | ANTENNA.**
Clock	Text			Broadcast in	**B:** *PROCESS* button, SPP or PPP in post-

	string			SPP, 5 Minutes in PPP/5 Minutes	mission only. **M: PROCESS** menu, SPP or PPP in post-mission only.
Clock Drift (Initial STD)	Float	Min.: 0 Max.: 10	m/s	1e2/1e5 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Clock Drift (Spectral Density)	Float	Min.: 0 Max.: 10	m^2/s^3	1e2/1e5 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Clock Offset (Initial STD)	Float	Min.: 0 Max.: 10	m	1e5/1e5 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Clock Offset (Spectral Density)	Float	Min.: 0 Max.: 10	m^2/s	1e5/1e5 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Code STD	Float	Min.: 0.01 Max.: 1	m	0.3/0.3	**B:** *SETUP* button, *Settings* tab **M: [1]SETUP | SETUP**, *Settings* tab or **[2]SETUP | SETTINGS.**
Coordinate System	Text string			Ellipsoidal /NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Date of Coordinates (yyyy)	Integer	Min.: 1900 Max.: 2100		2000/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Date of Coordinates (mm)	Integer	Min.: 1 Max.: 12		1/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Date of Coordinates (dd)	Integer	Min.: 1 Max.: 31		1/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Datum (Initial Coordinates)	Text string			WGS84/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Datum (Report)	Text string			WGS84/NA	**B:** *REPORT* button.
Elevation Mask	Float	Min.: 0 Max.: 90	degrees	10/10	**B:** *SETUP* button, *Settings* tab. **M: [1]SETUP | SETUP**, *Settings* tab or **[2]SETUP | SETTINGS.**
GDOP Mask	Float	Min.: 2 Max.: 100		20/20	**B:** *SETUP* button, *Settings* tab. **M: [1]SETUP | SETUP**, *Settings* tab or **[2]SETUP | SETTINGS.**
GPS UTC Offset	Integer	Min.: 1 Max.: 100	s	13/NA	**B:** *SETUP* button, *Settings* tab. **M: [1]SETUP | SETUP**, *Settings* tab or **[2]SETUP | SETTINGS.**
Horizontal	Float	Min.: 0 Max.: 10	m	1e2/1e0 if coords. are well	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button.

(Initial STD)	Integer	Min.: -20 Max.: 20		known, otherwise 1e2 (application specific)	**M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
Horizontal (Spectral Density)	Float	Min.: 0 Max.: 10	m^2/s	0e0/0e0 for static, 1e2 for kinematic (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Horizontal Vel. (Initial STD)	Float	Min.: 0 Max.: 10	m/s	1e1/1e2 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Horizontal Vel. (Spectral Density)	Float	Min.: 0 Max.: 10	m^2/s^3	1e1/1e2 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Height	Float	Min.: -1000 Max.: 100000	m	1116.00596/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Humidity	Float	Min.: 0 Max.: 100	%	50/NA	**B:** *SETUP* button, *Meteorology* tab. **M: [1]SETUP | SETUP**, *Meteorology* tab or **[2]SETUP | METEOROLOGY.**
Latitude (degrees)	Integer	Min.: -90 Max.: 90	degrees	51/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Latitude (minutes)	Integer	Min.: 0 Max.: 59	arcmin	4/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Latitude (seconds)	Float	Min.: 0 Max.: 59	arcsec	45.09418/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Longitude (degrees)	Integer	Min.: -180 Max.: 180	degrees	-114/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Longitude (minutes)	Integer	Min.: 0 Max.: 59	arcmin	7/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Longitude (seconds)	Float	Min.: 0 Max.: 59	arcsec	57.08383/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Marker to ARP (east)	Float	Min.: -10 Max.: 10	m	0/NA	**B:** *SETUP* button, *Antenna* tab. **M: [1]SETUP | SETUP,** *Antenna* tab or **[2]SETUP | ANTENNA.**
Marker to ARP (north)	Float	Min.: -10 Max.: 10	m	0/NA	**B:** *SETUP* button, *Antenna* tab. **M: [1]SETUP | SETUP,** *Antenna* tab or **[2]SETUP | ANTENNA.**
Marker to ARP (height)	Float	Min.: -10 Max.: 10	m	0/NA	**B:** *SETUP* button, *Antenna* tab. **M: [1]SETUP | SETUP,** *Antenna* tab or **[2]SETUP | ANTENNA.**
Observation Interval	Float	Min.: 0 Max.: 900	s	0/1	**B:** *SETUP* button, *Settings* tab. **M: [1]SETUP | SETUP**, *Settings* tab or **[2]SETUP | SETTINGS.**
Orbit	Text			Broadcast in	**B:** *PROCESS* button, SPP or PPP in post-

	string			SPP, SP3 in PPP /SP3	mission only. **M: PROCESS** menu, SPP or PPP in post-mission only.
Phase Rate STD	Float	Min.: 0.0001 Max.: 0.1	m/s	0.002/0.002	**B:** *SETUP* button, *Settings* tab. **M: [1]SETUP | SETUP**, *Settings* tab or **[2]SETUP | SETTINGS.**
Phase STD	Float	Min.: 0.0001 Max.: 0.1	m	0.002/0.002	**B:** *SETUP* button, *Settings* tab. **M: [1]SETUP | SETUP**, *Settings* tab or **[2]SETUP | SETTINGS.**
Pressure	Float	Min.: 500 Max.: 1200	millibars	1010/NA	**B:** *SETUP* button, *Meteorology* tab. **M: [1]SETUP | SETUP**, *Meteorology* tab or **[2]SETUP | METEOROLOGY.**
Temperature	Float	Min.: -100 Max.: 100	Degrees Celsius	15/NA	**B:** *SETUP* button, *Meteorology* tab. **M: [1]SETUP | SETUP**, *Meteorology* tab or **[2]SETUP | METEOROLOGY.**
Troposphere (Initial STD)	Float	Min.: 0 Max.: 10	m	1e-2/1e-2 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Troposphere (Spectral Density)	Float	Min.: 0 Max.: 10	m^2/s	1e-9/1e-9 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Vertical (Initial STD)	Float	Min.: 0 Max.: 10	m	1e2/1e0 if coords. are well known, otherwise 1e2 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Vertical (Spectral Density)	Float	Min.: 0 Max.: 10	m^2/s	0e0/0e0 for static, 1e2 for kinematic (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Vertical Vel. (Initial STD)	Float	Min.: 0 Max.: 10	m/s	1e1/1e2 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
Vertical Vel. (Spectral Density)	Float	Min.: 0 Max.: 10	m^2/s^3	1e1/1e2 (application specific)	**B:** *PROCESS* button, SPP or PPP, *FILTER SETTINGS* button. **M: PROCESS** menu, SPP or PPP, *FILTER SETTINGS* button.
	Integer	Min.: -20 Max.: 20			
X	Float	Min.: -∞ Max.: ∞	m	NA/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Y	Float	Min.: -∞ Max.: ∞	m	NA/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**
Z	Float	Min.: -∞ Max.: ∞	m	NA/NA	**B:** *SETUP* button, *Initial Coordinate* tab. **M: [1]SETUP | SETUP**, *Initial Coordinate* tab or **[2]SETUP | INITIAL COORDINATES.**

Appendix B: Ionospheric-Free Code and Phase Combinations

The purpose of this appendix is to familiarize the interested reader with some of the ionospheric-free code and phase combinations that have been implemented in P^3 for the Traditional Model and the UoC Model.

Traditional Model

The traditional carrier phase ionospheric-free combination, also known as the "L3" combination, is used in both the Traditional Model and the UoC Model. It is shown below, expressed in metric units.

$$\begin{aligned}\Phi_{IF} &= \frac{f_1^2 \cdot \Phi(L1) - f_2^2 \cdot \Phi(L2)}{f_1^2 - f_2^2} \\ &= \rho + c(dt - dT) + d_{orb} + d_{trop} + \frac{cf_1 N_1 - cf_2 N_2}{f_1^2 - f_2^2} + d_{mult/\Phi(L1+L2)} + \varepsilon(\Phi(L1+L2))\end{aligned} \qquad \text{B.1}$$

Where:

Φ_{IF}	–	Ionospheric-free carrier phase "L3" combination (m)
f_1	–	L1 frequency (1575.42 MHz)
f_2	–	L2 frequency (1227.60 MHz)
$\Phi(Li)$	–	Measured carrier phase on Li (m)
ρ	–	True geometric range (m)
c	–	Speed of light (m/s)
dt	–	Satellite clock error (s)
dT	–	Receiver clock error (s)
d_{orb}	–	Satellite orbit error (m)
d_{trop}	–	Tropospheric delay (m)
N_i	–	Integer phase ambiguity on Li (cycle)
$d_{mult/\Phi(L1+L2)}$	–	Multipath effect on the combined L1 and L2 phase observable (m)
$\varepsilon(\Phi(L1+L2))$	–	Measurement noise on the combined L1 and L2 phase observable (m)

Note that the ambiguity term is a linear combination of L1 and L2, and that it does not preserve the integer characteristics of the L1 and L2 ambiguities. The resulting combined ambiguity can only be estimated as a float value.

The equivalent pseudo-range L3 combination can be written as:

$$P(L3) = \frac{f_1^2 \cdot P(L1) - f_2^2 \cdot P(L2)}{f_1^2 - f_2^2} = \rho + c(dt - dT) + d_{orb} + d_{trop} + d_{mult/P(L3)} + \varepsilon(P(L3)) \quad \text{B.2}$$

Where:

$P(L3)$ – Ionospheric-free pseudorange "L3" combination (m)
$P(Li)$ – Measured pseudorange on Li (m)
$d_{mult/P(L3)}$ – Multipath effect on the combined L1 and L2 code observable (m)
$\varepsilon(P(L3))$ – Measurement noise on the combined L1 and L2 code observable (m)

Using L3 combinations has some disadvantages. First, the combinations are not totally ionosphere-free. They cannot remove higher-order ionospheric effects, although these are usually less than 0.1% of the total ionospheric effect. Nevertheless, they can still introduce several decimetres of range error during times of high Total Electron Content (TEC). Second, the noise level of the L3 combination increases by nearly a factor of three as compared to the noise level of the corresponding original code and carrier phase observables.

UoC Model

The UoC observation model includes code-phase combinations on both L1 and L2 frequencies, together with the traditional ionosphere-free phase combination (Equation B.5). They have the following expressions:

$$P_{IF,L1} = \frac{1}{2}(P(L1) + \Phi(L1)) = \rho + c(dt - dT) + d_{orb} + d_{trop} + \frac{1}{2}\lambda_1 N_1 + \frac{1}{2}d_{mult/P(L1)} + \frac{1}{2}\varepsilon(P(L1) + \Phi(L1)) \quad \text{B.3}$$

$$P_{IF,L2} = \frac{1}{2}(P(L2) + \Phi(L2)) = \rho + c(dt - dT) + d_{orb} + d_{trop} + \frac{1}{2}\lambda_2 N_2 + \frac{1}{2}d_{mult/P(L2)} + \frac{1}{2}\varepsilon(P(L2) + \Phi(L2)) \quad \text{B.4}$$

$$\Phi_{IF} = \frac{f_1^2 \cdot \Phi(L1) - f_2^2 \cdot \Phi(L2)}{f_1^2 - f_2^2} = \rho + c(dt - dT) + d_{orb} + d_{trop} + \frac{cf_1 N_1 - cf_2 N_2}{f_1^2 - f_2^2} + d_{mult/\Phi(L1+L2)} + \varepsilon(\Phi(L1+L2)) \quad \text{B.5}$$

This observation model, compared with the one applied in the Traditional Model, has lower noise and a lower error residual level. The most significant advantage, however, is the possibility of estimating fixed ambiguities, since the L1 and L2 ambiguities are not lumped together in one term. As such, ambiguity searching and fixing techniques can be implemented. In turn, this will further improve positioning convergence due to a reduced number of unknown parameters. However, ambiguity resolution algorithms have not been implemented in this version of P^3.

Appendix C: Ambiguity Estimation in Traditional and UoC Models

Ambiguity estimation is done in the Traditional and UoC Models, which are implemented in either real-time or post-mission PPP mode. The numerical difference between code and phase observations is equivalent to the phase ambiguity if all the errors are corrected. Although GPS errors cannot be removed completely, the difference can still be a good approximation to the phase ambiguity.

TRADITIONAL MODEL

In the Traditional Model, the ionospheric-free code and carrier phase combinations are used to approximate the combined ambiguity term, which contains both L1 and L2 ambiguities. Applying precise orbit and clock corrections to Equations B.1 and B.2 from Appendix B results in the following equations:

$$P'_{IF} = \rho - c \cdot dT + d_{trop} + \varepsilon'(P_{IF}) \qquad \text{C.1}$$

$$\Phi'_{IF} = \rho - c \cdot dT + d_{trop} + N' + \varepsilon'(\Phi_{IF}) \qquad \text{C.2}$$

Where:

P'_{IF} – Corrected ionosphere-free code observable (m)

Φ'_{IF} – Corrected ionosphere-free phase observable (m)

N' – Combined ambiguity term (m)

$\varepsilon'(\ )$ – Random noise component, including multipath, noise, and residual errors of precise orbit and clock data (m)

An estimation of the combined ambiguity term is done using the following formula:

$$N' = P'_{IF} - \Phi'_{IF} \qquad \text{C.3}$$

This is used as an approximate value in the least-squares process, which itself estimates the combined ambiguity at each epoch for each satellite.

UoC MODEL

In the UoC Model, the L1 and L2 ambiguities are estimated separately. The following equation provides an approximate initialization of the L_1 ambiguity with the ionospheric effect calculated using dual frequency code observations.

$$\begin{aligned}\lambda_1 N_1 &= P(L_1) - \Phi(L_1) - 2 \cdot d_{ION}(L_1) \\ &= P(L_1) - \Phi(L_1) - 2 \cdot (P(L_1) - P(L_2)) \left(\frac{f_2^2}{f_2^2 - f_1^2} \right) \\ &= \left(1 + \frac{2 \cdot f_2^2}{f_1^2 - f_2^2}\right) \cdot P(L_1) - \frac{2 \cdot f_2^2}{f_1^2 - f_2^2} \cdot P(L_2) - \Phi(L_1)\end{aligned} \qquad \text{C.4}$$

Similarly, an approximate initialization of the L_2 ambiguity with the ionospheric effect calculated using dual frequency code observations is given by:

$$\begin{aligned}\lambda_2 N_2 &= P(L_2) - \Phi(L_2) - 2 \cdot d_{ION}(L_2) \\ &= P(L_2) - \Phi(L_2) - 2 \cdot (P(L_1) - P(L_2)) \left(\frac{f_1^2}{f_2^2 - f_1^2} \right) \\ &= \frac{2 \cdot f_1^2}{f_1^2 - f_2^2} \cdot P(L_1) + (1 - \frac{2 \cdot f_1^2}{f_1^2 - f_2^2}) \cdot P(L_2) - \Phi(L_2)\end{aligned} \qquad \text{C.5}$$

These approximate values are used in the least-squares process, which then estimates both L_1 and L_2 ambiguities for each satellite at each epoch.

Appendix D: Phase Smoothing of Code

Phase smoothing of code reduces the code noise level by applying the following recursive smoothing procedure:

$$\begin{aligned} P_{SM,Li}(n) &= \frac{1}{m} P_{IF,Li}(n) + \left(1 - \frac{1}{m}\right)\left(P_{SM,Li}(n-1) + \Phi_{IF}(n) - \Phi_{IF}(n-1)\right) \\ &= \rho + c(dt - dT) + d_{orb} + d_{trop} + d_{mult} + \frac{1}{2}\lambda_i N_i + \varepsilon\left(P_{SM,Li}(n)\right) \end{aligned} \qquad \text{D.1}$$

Where:

$P_{SM,Li}(n)$	–	Smoothed L_i code measurement at epoch *n* (m)
$P_{SM,Li}(n-1)$	–	Smoothed L_i code measurement at epoch *n-1* (m)
$P_{IF,Li}(n)$	–	Ionospheric-free L_i code combination at epoch *n* (m)
$\Phi_{IF}(n)$	–	Ionospheric-free phase combination at epoch *n* (cycle)
$\Phi_{IF}(n-1)$	–	Ionospheric-free phase combination at epoch *n* (cycle)
ρ	–	True geometric range (m)
c	–	Speed of light (m/s)
dt	–	Satellite clock error (s)
dT	–	Receiver clock error (s)
d_{orb}	–	Satellite orbit error (m)
d_{trop}	–	Tropospheric delay (m)
d_{mult}	–	Multipath (m)
λ_i	–	L_i wavelength (m)
N_i	–	Integer phase ambiguity on Li (cycle)
$\varepsilon\left(P_{SM,Li}(n)\right)$	–	Smoothed L_i code measurement noise at epoch *n* (m)
m	–	Total number of data epochs that have been used to derive the smoothed observable (assuming no cycle slips have occurred)
n	–	Epoch index

Both the multipath effect and the noise can be significantly reduced with this smoothing process.

Appendix E: References

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